Original Research

Impulse oscillometry and whole-body plethysmography parameters are correlated in healthy children: a cross-sectional study

Correlação entre parâmetros da oscilometria de impulso e pletismografia de corpo inteiro em crianças saudáveis: um estudo transversal

Tayná Castilho[1]; Renata Maba Gonçalves Wamosy[2]; Fabiula Joanita da Mata Belém[2]; Tatiana Godoy Bobbio[3]; Camila Isabel Santos Schivinski[2]*

[1]Programa de Pós-Graduação em Saúde da Criança e do Adolescente, Universidade Estadual de Campinas, Campinas, SP, Brasil
[2]Departamento de Fisioterapia, Universidade do Estado de Santa Catarina, Florianópolis, SC, Brasil
[3]Physical Therapy Program, University of St. Augustine for Health Sciences, Miami, Florida, United States of America

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***Corresponding author:** Camila Isabel Santos Schivinski. E-mail: cacaiss@yahoo.com.br

Abstract

Background: The whole-body plethysmography (WBP) is the gold standard for verifying pulmonary function, assessing the airway resistance and the pulmonary volume and capacities through a forced expiratory maneuver. In turn, the airway resistance assessment can be performed through the impulse oscillometry system (IOS) during tidal breathing. The question therefore arises as to whether these evaluations have any correlation. **Aim:** The main objective is to investigate the correlation between the WBP and IOS variables in healthy children. The secondary objective is to investigate the correlation between WBP resistance parameters and lung volumes and capacity parameters. **Methods:** Cross-sectional analytical study including healthy children between seven to 14 years old from private and public schools in Brazil. The children's respiratory system was evaluated through IOS and WBP, and the following parameters were registered: By IOS, impedance at 5 Hz (Z5), total airway resistance, central airway resistance, and reactance at 5 Hz; By WBP, airway resistance (Raw), specific airway resistance (sRaw), total airway resistance, inspiratory capacity, expiratory reserve volume, plethysmography functional residual capacity, vital capacity, residual volume (RV), total lung capacity, forced vital capacity, forced expiratory volume in one second (FEV_1), and forced expiratory flow of 25% to 75% of forced vital capacity. Pearson and Spearman's Correlation Coefficients (r and r_s, respectively) were used to investigate the correlations between IOS and WBP parameters. **Results:** Sixty-one children with an average age of 9.57±2.06 years, 54% female individuals, participated in this study. There were significant correlations between IOS and most WBP parameters (r/r_s=0.256-0.702, p≤0.05 for all, except for sRaw and RV). In turn, the oscillometry parameter Z5 showed the strongest correlation with a WBP parameter (r=-0.702 with FEV_1). Moreover, Raw presented a correlation to other WBP parameters (r/r_s≥0.330). **Conclusion:** IOS parameters showed weak-to-moderate correlations with most WBP parameters in healthy children.

Keywords: Child; Adolescent; Pulmonary Function Test; Respiratory Mechanics.

Resumo

Introdução: A pletismografia de corpo inteiro (PCI) é considerada a avaliação padrão-ouro para verificar a função pulmonar, medindo a resistência das vias aéreas, bem como os volumes e capacidades pulmonares por meio de uma manobra expiratória forçada. Por outro lado, a resistências das vias aéreas pode ser realizada por meio do sistema de oscilometria de impulse (IOS) durante respiração em volume corrente. Sendo assim, surge uma questão referente a exixtência de uma correlação entre essas duas avaliações. **Objetivo:** O objetivo principal é investigar a correlação entre as variáveis da PCI e do IOS em crianças saudáveis. O objetivo secundário é investigar a correlação entre os parâmetros de resistência e de volumes e capacidades pulmonoares do PCI. **Métodos:** Estudo analítico e transversal, que incluiu crianças saudáveis entre sete e 14 anos de idade de escolas públicas e privadas do Brasil. O sistema respiratório das crianças foi avaliado por meio do IOS e PCI, e os seguintes parâmetros foram registrado: IOS, impedância a 5Hz (Z5), resistência total e central das vias aéreas, e reatância a 5Hz; PCI, resistência das vias aéreas (Raw), resistência específica das vias aéreas (sRaw), resistência total das vias aéreas, capacidade inspiratória, volume de reserve expiratório, capacidade residual functional pletismográfica, capacidade vital, volume residual (RV), capacidade pulmonar total, capacidade vital forçada, volume expiratório forçado no primeiro Segundo (VEF1), e fluxo expiratório forçado de 25% a 75% da capacidade vital forçada. Coeficiente de correlação de Pearson e Spearman

(r e r_s, respectivamente) foram usados para investigar as relações entre os parâmetros do IOS e PCI. **Resultados:** Participaram do estudo 61 crianças com média de idade de 9,57±2,06 anos, sendo 54% do sexo feminino. Houve correlação entre IOS e PCI parâmetros (r/r_s=0,256-0,702, p≤0,05 para todos, exceto para sRaw e RV). No entanto, o parâmetro oscilométrico Z5 apresentou a correlação mais forte com parâmetro da PCI (r=-0,702 com FEV_1). Além disso, Raw apresentou correlação com outros parâmetros da PCI (r/r_s≥0,330). **Conclusão:** parâmetros do IOS apresentaram correlações de fraca a moderada com a maioria dos parâmetros da PCI, em crianças saudáveis.

Palavras-chave: Criança; Adolescente; Teste de Função Pulmonar; Mecânica Respiratória.

INTRODUCTION

The whole-body plethysmography (WBP) assesses pulmonary function through static lung volumes and determines airway resistance. Therefore, it allows to measure residual volume (RV), functional residual capacity (FRC), and total lung capacity (TLC)[1,2]. The individual inside a cabin breaths through a mouthpiece, and then the occlusion maneuver is applied, followed by a forced expiration to obtain these parameters[1]. Thus, this method detects the cabin pressure changes due to variations in mouth pressure and respiration flow[2]. Unfortunately, although such an assessment is recommended for this population, the literature has gaps regarding the application of this methodology in children[3].

Another method used to assess respiratory mechanics is the Impulse Oscillometry System (IOS), which provides information regarding peripheral and central airway resistance and airway reactance[4]. However, the IOS parameters are not obtained through mouth occlusion or forced expiration as in the WBP. The IOS generates pulse frequencies, varying from five to 30Hz, that are propagated through the respiratory system while the individual breaths in tidal volume[5]. Hence, the IOS is considered a rapid method that could be applied as a complementary assessment to spirometry[4].

Both assessments can be used to assess children's respiratory systems, especially those with chronic respiratory diseases, such as asthma and cystic fibrosis[4,6]. Nonetheless, the relationship between WBP and IOS parameters must be investigated, as these methods evaluate the individual in different breathing conditions, such as during forced expiration or tidal volume, respectively. It is important to evaluate how these parameters perform and whether they correlate in healthy children and adolescents for a better understating of the behavior of these parameters in individuals with respiratory system impairment. In addition, such analyses might enable to compare different health conditions and provide data to identify inadequate behavior of these parameters. Thereby, this study aimed to investigate the correlation between the WBP and IOS variables in healthy children. As a secondary objective, we sought to investigate the correlation between WBP resistance parameters and lung volumes and capacities parameters.

METHODS

Study design and subjects

This is a cross-sectional analytical study approved by the Santa Catarina State University (UDESC) Research Ethics Committee (CAAE: 52891215.7.0000.0118) and registered in the Brazilian Clinical Trial Registry (ReBEC) (RBR-96MZ5C). The participants were recruited in private and public schools, and data collection occurred between 2016 and 2017 in the Physiotherapy School Clinic of UDESC, in Florianópolis, Santa Catarina – Brazil. In addition, all participants and their parents/guardians were given a written informed consent. This study report followed the STROBE checklist.

The following inclusion criteria were applied: healthy schoolchildren between seven and 14 years old, without any congenital, cardiorespiratory, musculoskeletal, rheumatic, and/or neurological diseases, hearing or visual deficits. The following exclusion criteria were applied: the presence of acute respiratory disease on the data collection day, forced expiratory volume in one second (FEV_1) lower than 80% of predicted, inability to perform adequately any of the assessment procedures, and/or claustrophobia in the WBP cabin.

Data collection procedures

Information concerning the children's personal and health data was given by their parents or guardians and registered in an evaluation form. Module I of The International Study and Allergies in Childhood (ISAAC) questionnaire was used to identify the presence of asthma, based on the following cutoff points: more than five points to children between six and nine years old, and more than six points to children between ten and 12 years old[7] Anthropometric measures such as weight and height were collected, followed by the calculation of the body mass index (BMI)[8].

Impulse oscillometry

Respiratory mechanics assessment was performed through the pneumatograph MasterScreen IOS (Erich Jaeger, Würtzburg, Germany®), according to the American Thoracic Society (ATS) recommendations[9]. Three IOS measurements of 30 seconds were registered, during which the parameters should not change by more than

10%. The measurements were considered valid upon the absence of artifacts such as coughing, swallowing, or speaking. The first valid measurement was chosen for analysis. The following oscillometry parameters were registered: impedance at 5Hz (Z5), reactance at 5Hz (X5), and total (R5) and central (R20) airway resistance. All parameters were presented in absolute and predicted percentages (pred%) values according to the Assumpção et al. reference equation[10].

Whole-Body Plethysmography (WBP)

WBP assessment was performed through the pneumatograph MasterScreen Body (*Eric Jaeger – MasterScreen Body Germany*® 234 GmbH), according to the European Respiratory Society (ERS) recommendations[11], after the IOS assessment. The assessment was performed inside a cabin, where children were instructed to breathe through a mouthpiece, in an upright position, with knees at 90 degrees and feet flat on the floor.

The following parameters were registered in absolute values: airway resistance (Raw – kpa/L/s), specific airway resistance (sRaw- kpa*s), and total airway resistance (Rtot – kPa*s). The lung volumes and capacities were registered in absolute and predicted percentage values, according to the Global Lung Function Initiative (GLI) reference values[12]: inspiratory capacity (IC), expiratory reserve volume (ERV), plethysmography functional residual capacity (FRCpleth), vital capacity (VC), residual volume (RV), total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and forced expiratory flow of 25% to 75% of FVC (FEF_{25-75}).

Statistical analysis

Data were analyzed on the IBM SPSS version 20.0© software (IBM, Armonk, NY, USA), in the form of graphics and tables. The Kolmogorov-Smirnov test was used to verify the data distribution. Pearson's correlation coefficient was used to investigate the correlation between variables and normal distribution, and the correlation coefficients were classified according to Dancey and Reidy[13]: 0.10 to 0.39, weak; 0.40 to 0.69, moderate; and 0.70 to 1.0, strong. Spearman's correlation coefficient was used for variables with non-normal distribution. The significance level for all tests was set at 5%. the power of Pearson's correlation coefficient between R5 and Raw parameters in a sample of 61 individuals was calculated on the G*Power software (Heinrich Heine University, Dusseldorf, Germany) , whose results showed a power of 84%.

RESULTS

Sixty-one children participated in this study, out of which 33 were girls. Table 1 presents the sample characteristics. IOS and WBP data are expressed in absolute and predicted percentage values in Table 2.

Table 1. Sample characteristics.

Characteristic	Value
Female, n (%)	33 (54.1)
Age, years	9.57 ± 2.06
Weight, kg	37.48 ± 9.97
Height, cm	1.41 ± 0.11
BMI, kg/m²	18.21 ± 3.20
BMI classification, n (%)	
Thinness	1 (1.6)
Eutrophic	37 (60.7)
Overweight	17 (27.9)
Obesity	6 (9.8)

BMI: Body Mass Index. Data are expressed as absolute and relative frequency or mean ± standard deviation.

Table 3 shows the correlation analysis for the respiratory system parameters. The oscillometry parameters presented a statistically significant correlation with most WBP parameters. RV and sRaw showed no significant correlation with IOS parameters; in addition, Rtot showed no significant correlation with X5.

FRCpleth, ERV, VC, TLC, FVC, FEV_1, and FEF_{25-75} presented moderate correlations with all IOS parameters. Regarding FEV_1, this parameter showed the strongest correlation with Z5 (r=-0.702) and moderate correlations with R5, R20, and X5 (r=0.551-0.691). Additionally, there were significant correlations between Raw and oscillometry parameters; however, they were classified as weak (r=0.256-0.378).

Table 4 shows the correlation analysis between WBP airway resistance parameters and WBP lung volumes and capacities. Raw and Rtot showed significant correlations with all other WBP parameters. There was a moderate correlation between Raw and FRCpleth, IC, TLC, FEV_1, and FEF_{25-75}. The sRaw parameter showed no correlation with any of the other WBP parameters.

DISCUSSION

This study identified statistically significant correlations between the WBP and IOS parameters for lung function assessment, being among the few studies investigating such a relationship in the pediatric population. Thus, we highlight the relevance of this research as the use of IOS has been increasing in this age group. In addition, the IOS presents favorable features such as simplicity and ease of execution, capacity to evaluate peripheral airway, and sensitivity to identify early alveolar involvement[4]. Still, the IOS device is operationally less complex and less costly than the WBP, which requires a cabin and adequate physical space.

Tomalak et al.[14] analyzed the relationship between IOS and WBP parameters in the pediatric population. Their

Table 2. IOS and WBP parameters expressed in absolute and predicted percentage values.

Parameter	Value	Parameter	Value
Z5, kPas/L/s	0.67 ± 0.17	**FRCpleth, L**	1.84 ± 0.47
Z5, %	157.67 ± 38.70	**FRCpleth, %**	121.88 ± 20.28
R5, kPas/L/s	0.65 ± 0.16	**VC, L**	2.34 ± 0.55
R5, %	108.22 ± 21.07	**VC, %**	92.25 ± 10.30
R20, kPas/L/s	0.50 ± 0.10	**RV, L**	0.63 ± 0.18
R20, %	101.62 ± 19.68	**RV, %**	87.39 ± 25.76
X5, kPas/L/s	-0.18 ± 0.07	**TLC, L**	2.95 ± 0.622
X5, %	124.59 ± 43.07	**TLC, %**	97.68 ± 10.45
sRaw, kPa*s	0.80 ± 0.25	**FVC, L**	2.33 ± 0.57
Rtot, kPa*s	0.65 ± 0.30	**FVC, %**	100.31 ± 11.77
Raw, kPa/L/s	0.46 ± 0.17	**FEV_1, L**	2.02 ± 0.48
IC, L	1.42 ± 0.36	**FEV_1, %**	99.32 ± 11.29
IC, %	94.00 ± 17.66	**FEF_{25-75}, L/s**	2.30 ± 0.64
ERV, L	0.89 ± 0.31	**FEF_{25-75}, %**	93.23 ± 19.23
ERV, %	119.24 ± 28.97	--	--

Z5: impedance at 5 Hz; R5: total airway resistance; R20: central airway resistance; X5: reactance at 5 Hz; Raw: airway resistance; sRaw: specific airway resistance; Rtot: total airway resistance; IC: inspiratory capacity; ERV: expiratory reserve volume; FRCpleth: plethysmography functional residual capacity; VC: vital capacity; RV: residual volume; TLC: total lung capacity; FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; FEF_{25-75}: forced expiratory flow of 25% to 75% of FVC. Data are presented as mean ± standard deviation.

Table 3. Pearson and Spearman's Correlation Coefficients between IOS and WBP parameters in absolute values.

Parameters	Z5 (kPa/L/s)	R5 (kPa/L/s)	R20 (kPa/L/s)	X5 (kPa/L/s)
Raw (kPa/L/s)	0.378	0.366	0.256	-0.331
Rtot (kPa*s)	0.405s	0.403s	0.372s	NS
sRaw (kPa*s)	NS	NS	NS	NS
FRCpleth (L)	-0.553	-0.547	-0.511	0.422
IC (L)	-0.408	-0.398	-0.384	0.338
ERV (L)	-0.654s	-0.652s	-0.570s	0.555s
VC (L)	-0.650	-0.639	-0.584	0.514
RV (L)	NS	NS	NS	NS
TLC (L)	-0.623	-0.618	-0.546	0.444
FVC (L)	-0.643	-0.631	-0.579	0.516
FEV_1 (L)	-0.702	-0.691	-0.629	0.551
FEF_{25-75} (L/s)	-0.532s	-0.516s	-0.487s	0.531s

s: Spearman correlation coefficient; NS: statistically non-significant; Z5: impedance at 5 Hz; R5: total airway resistance; R20: central airway resistance; X5: reactance at 5 Hz; Raw: airway resistance; sRaw: specific airway resistance; Rtot: total airway resistance; IC: inspiratory capacity; ERV: expiratory reserve volume; FRCpleth: plethysmography functional residual capacity; VC: vital capacity; RV: residual volume; TLC: total lung capacity; FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; FEF_{25-75}: forced expiratory flow of 25% to 75% of FVC. Data are presented as statistically significant correlation coefficients.

study aimed to compare the airway resistance assessed by the two methods and included 337 children (between five and 18 years old) with different chronic respiratory diseases. The authors found Raw values lower than R5, R20, and resistance at 35Hz (R35) in healthy children, which seems to corroborate the our results . The authors also

Table 4. Pearson and Spearman's Correlation Coefficients between WBP resistance parameters and lung volumes and capacities in absolute values.

Parameters	Raw (kPa/L/s)	Rtot (kPa*s)	sRaw (kPa*s)
FRCpleth (L)	-0.503	-0.664s	NS
IC (L)	-0.415	-0.427s	NS
ERV (L)	-0.330s	-0.484s	NS
VC (L)	-0.399	-0.491s	NS
RV (L)	-0.336	-0.394s	NS
TLC (L)	-0.466	-0.547s	NS
FVC (L)	-0.386	-0.481s	NS
FEV_1 (L)	-0.424	-0.525s	NS
FEF_{25-75} (L/s)	-0.488s	-0.564s	NS

s: Spearman correlation coefficient; NS: statistically non-significant; Raw: airway resistance; sRaw: specific airway resistance; Rtot: total airway resistance; IC: inspiratory capacity; ERV: expiratory reserve volume; FRCpleth: plethysmography functional residual capacity; VC: vital capacity; RV: residual volume; TLC: total lung capacity; FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; FEF_{25-75}: forced expiratory flow of 25% to 75% of FVC. Data are presented as statistically significant correlation coefficients.

identified moderate correlations between IOS parameters and Raw and FEV_1, whereas the correlation between R5 and Raw showed the highest value (r=0.64)[14].

Hellinckx et al.[15] compared the airway resistances assessed by different methods (IOS, WBP, and forced oscillation technique) and investigated their correlation in 49 individuals between eight and 70 years old, with and without respiratory disease. The authors found a moderate correlation between Raw and R5 (r=0.59); however, the Raw values were lower than those of the R5, like in Tomalak et al.[14] and our study.

Herein, Raw correlated to all IOS parameters, but the correlations were classified as weak. The weak correlation (r=0.366) found herein in the Raw and R5 analysis differs from that reported by Tomalak et al.[14] and Hellinckx et al.[15], who found a moderate correlation between these parameters. However, such differences might be linked to Tomalak et al. and Hellinckx et al. including individuals covering a larger age group and more respiratory diseases[14,15]. Therefore, further investigations involving these two methods must cover different populations, such as children with and without respiratory conditions.

The sRaw parameter showed no significant correlation with any IOS or WBP parameters of lung volumes and capacities. sRaw is the first parameter measured in WBP and is used to calculate Raw, which is determined by the sRaw and FRCpleth ratio[2]. According to Criée et al.[2], sRaw is not considered a resistance measure since it is not calculated through a volume unit, which is required to determine flow and resistance value. This could explain why the sRaw showed no correlation with any other WBP or IOS parameters, as observed in our study. Thus, further investigations should focus on understanding this parameter as a resistance measure in children as it requires no occlusion maneuvers or forced expiration.

In our study, the highest correlation values (≥0.6) occurred between the Z5 and R5 IOS parameters, and some lung volumes and capacities parameters (VC, TLC, FVC, FEV_1). In addition, FEV_1 and Z5 presented the strongest correlation. Some prior studies found correlations between IOS parameters and FVC and FEV_1[16,17] as well. However, correlations between IOS parameters and VC and TLC are relevant, suggesting that the IOS may be used as a complementary tool to assess lung function considering the better correlation between the IOS and the WBP than that between the Raw and the WBP.

None of the studies that investigated correlations between the IOS and WBP parameters considered the Z5 parameter in their analysis[14,15,18–20]. In our investigation, the Z5 is the oscillometry parameter with the highest correlation values with WBP parameters. Such a finding might indicate that the Z5 should be considered for lung function assessment for referring to the whole airway and corresponding to the sum of airway resistance and reactance[4]. Therefore, further investigations should focus on understanding the relationship between the Z5 and WBP parameters and verifying how the Z5 performs in children with specific respiratory conditions.

As to the study limitations, it is worth highlighting that the sample includes no individuals with respiratory system impairment, which could be interesting to compare the data with healthy children and adolescents.

In conclusion, weak-to-moderate correlations occurred between the IOS and WBP parameters in children without respiratory impairments. Furthermore, the IOS parameters seem to have a stronger correlation with lung volume and capacity parameters than the airway resistance assessed through WBP.

How can the results of this study be used in clinical practice?

- IOS parameters, such as Z5 and R5, showed stronger correlations with spirometric parameters (VC, FVC, and FEV_1) compared to the Raw (a WBP parameter).
- IOS can be used as a complement to spirometry evaluation.

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CONFLICT OF INTEREST

None.

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