



Original Article

Differences in Airway Resistances in Children Measured by Plethysmography With and Without Closure of the Occluder

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ABSTRACT

Background: There have been several studies that have measured airway resistances using plethysmography without closing the occluder

Objective: To investigate the differences between the total resistances ($sRaw_{TOT}$) and the specific resistances ($sRaw$) with the same technique (plethysmography) but different methodology (with and without closure of the occluder) in child subjects.

Material and methods: An observational and cross-sectional study of a consecutive sample of children between 6 and 14 years old who were seen at the Childhood Pneumology clinics from 15th January to 15th February 2009. Determination of $sRaw_{TOT}$, $sRaw$ and specific conductance ($sGaw$) using plethysmography (MasterLab V5.1, Viasys®, Wuerzburg, Germany) without closing the occluder. The same determinations were then performed with the occluder closed. The qualitative variables were: sex, diagnosis and treatment, and the quantitative variables: age, weight, height, $sRaw_{TOT}$, $sRaw$, $sGaw$ and respiratory rate with and without closing the occluder. The results were analysed for association and concordance between $sRaw_{TOT}$, $sRaw$ and $sGaw$ with and without closure of the occluder using paired Student t test, Bland-Altman method and a scatter plot.

Results: Thirty-six cases were included and all (100%) the tests were performed successfully. The mean age was 9.91 ± 2.37 years. There were no differences between $sRaw_{TOT}$, $sRaw$ or $sGaw$ with and without closure of the occluder. Neither were there any differences between the regression of the means obtained for $sRaw_{TOT}$, $sRaw$ and $sGaw$ with and without closure of the occluder.

Conclusions: There is good agreement between the $sRaw_{TOT}$ and $sRaw$ obtained by plethysmography with and without closure of the occluder.

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Concordancia en niños entre las resistencias de la vía aérea medidas mediante pletismografía con y sin cierre del ocluser

RESUMEN

Antecedentes: Diversos investigadores han estudiado las resistencias de la vía aérea mediante pletismografía sin cierre del ocluser.

Objetivo: Comprobar la concordancia entre las resistencias totales ($sRaw_{TOT}$) y las resistencias específicas ($sRaw$) con la misma técnica (pletismografía) y diferente metodología (con y sin cierre del ocluser) en niños colaboradores.

Material y métodos: Estudio observacional y transversal de una muestra consecutiva de niños entre 6 y 14 años que acudieron a consultas de Neumología Infantil, desde el 15 de enero hasta el 15 de febre-

Palabras clave:

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ro de 2009. Determinación de $sRaw_{TOT}$, $sRaw$ y conductancia específica ($sGaw$) mediante pletismografía (MasterLab V5.1, Viasys®, Wuerzburg, Alemania) sin cierre del ocluser. En todos se realizaron a continuación las mismas determinaciones con cierre del ocluser. Variables cualitativas: sexo, diagnóstico y tratamiento, y variables cuantitativas: edad, peso, talla, $sRaw_{TOT}$, $sRaw$, $sGaw$ y FR con y sin cierre del ocluser. Análisis de la asociación y concordancia entre $sRaw_{TOT}$, $sRaw$ y $sGaw$ con y sin cierre del ocluser mediante t de Student pareada, método Bland-Altman y diagrama de puntos (Scatter plot).

Resultados: Se incluyeron 36 casos. El 100% realizó las pruebas con éxito. Edad media: $9,91 \pm 2,37$ años. No hubo diferencias entre $sRaw_{TOT}$, $sRaw$ ni $sGaw$ con y sin cierre del ocluser. Tampoco hubo diferencias entre la regresión de las medias obtenidas de $sRaw_{TOT}$, $sRaw$ y $sGaw$ con y sin cierre del ocluser, respecto a la diferencia de las mismas.

Conclusiones: Existe una buena concordancia entre $sRaw_{TOT}$ y $sRaw$ obtenidas por pletismografía con y sin cierre del ocluser.

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Introduction

In recent years, there have been numerous studies on the development of new methodologies for paediatric lung function, especially directed toward uncooperative children.¹ Of these, total body plethysmography remains the gold standard in the study of lung function. It measures the different volumes of gas, such as residual volume (RV), functional residual capacity (FRC) and total lung capacity (TLC). Furthermore, it quantifies the total resistance ($sRaw_{TOT}$), the specific airway resistance ($sRaw$), conductance and specific airway conductance ($sGaw$).²

Resistance is defined as the ratio between the flow of air through the airways and the pressure that needs to be exerted to produce that flow. The $sRaw_{TOT}$ includes the resistance of the thoracic wall, the lung tissue and the airways. The $sRaw$ is the product of the airway resistance and the FRC. With the growth and development during the first decade of life and in successive years, resistances decrease and lung volumes increase, but the $sRaw$ remains relatively stable and varies little with age.³ Therefore, $sRaw$ is a sensitive and reliable parameter for discriminating between normal function and disease, and between pathologies with similar symptoms.⁴

Plethysmography is a complex technique that in general requires cooperative children, that is, over the age of 6 years. It requires that the child be seated in a sealed booth and made to breathe through a rigid mouthpiece and a pneumotachograph. Subsequently, the occluder is closed to determine the gas volumes. Furthermore, a compensation for the warming and humidification process needs to be performed, which can be done by means of a *panting* procedure (hyperventilation with an increase in respiratory rate [RR] between 90-180 resp/min) or by means of a simulation of body temperature and barometric pressure at water vapour saturation conditions (BTPS)². The parameters obtained, corrected under BTPS conditions, can be done under normal respiration by means of heated rebreathing air (HRB), considered the gold standard, or with electronic compensation (EC)³. Currently the majority of plethysmographs perform EC automatically.

In the 1970s, Dab et al^{5,6} published for the first time the simplification of the technique for determining $sRaw$ by means of plethysmography in one single manoeuvre at a normal breathing rate, without closing the occluder (which prevents the reading of lung volumes) and without sedation, with good reproducibility. Subsequently, other authors have documented this reproducibility in children under six years using a simplified technique adjusted under BTPS and EC conditions with an RR between 30-45 breaths per minute, with a face mask or mouthpiece and nose clip, with or without an accompanying adult inside the booth.^{7,8}

The objective of this study was to test, as other researchers have done, the correlation between total and specific airway resistance obtained using the same technique (plethysmography) and different

methodologies (with or without closure of the occluder) to validate the pulmonary technique and software used in our laboratory for further development in children under 6 years of age.

Material and Methods

Cross-sectional observational study of a consecutive sample of patients aged 6-14 years attending outpatient child pulmonology visits from 15 January to 15 February 2009.

All cases included initial determinations of $sRaw_{TOT}$, $sRaw$ and $sGaw$ by means of total body plethysmography (MasterLab V5.1, Viasys®, Wuerzburg, Germany) without closing the occluder.

According to version 5.1 of the software (Viasys® ISM 2005), $sRaw_{TOT}$ (Ulmer) is considered to be the value obtained from connecting the maximum precision points, and $sRaw$ (Matthys) is that calculated by the slope throughout all respiration. The patient was seated in the hermetically sealed booth with mouthpiece and nose clip in place and neck slightly hyperextended. The $sRaw$ was calculated based on the relationship between the extent of changes in respiratory flow and the changes in volume inside the booth ($sRaw = \Delta V_{\text{booth}} / \Delta V_x [P_{\text{amb}} - P_{H_2O}]$). During the procedure, the pressure-flow curves obtained were displayed in real time on the computer screen, allowing the technician to eliminate those curves containing artefacts produced by speech, coughing, swallowing, apnoea or irregular breathing patterns. The curves were required to have similar size and shape, to be parallel and to be close to zero flow. The tangent automatically selected by the computer is then used. The determinations of total and specific resistance were obtained after calculating the mean of 5 valid readings during the same functional exploration. The readings were adjusted under BTPS conditions with EC.⁹

First, in all cases included in this study the same readings were performed with closure of the occluder, as recommended by ATS/ERS.² RR ranges between 30-45 breaths per minute were used. To ensure reproducibility of the technique, at least 3 FRC readings were performed with a difference of less than 5% between them.

Qualitative variables studied were gender, diagnosis and treatment (represented in absolute numbers and percentage). Quantitative variables were age, weight, height, $sRaw_{TOT}$ (Ulmer), $sRaw$ (Matthys), $sGaw$ and RR, with or without closure of the occluder (represented as mean \pm SD). The association and correlation between $sRaw_{TOT}$, $sRaw$ and $sGaw$ in absolute values, with and without closure of the occluder, were studied through paired Student's t tests (mean difference \pm SD), the Bland-Altman's graphical method and dot plots (Scatter plot). Similarly, the variability between RR at which the readings were made with or without closure of the occluder was studied through the paired Student's t test (mean difference \pm SD). In all cases, an alpha level of 5% was established. The statistical package SYSTAT 9.0™ was used.

The study was approved by the Research Ethics Committee of the hospital where the study was performed. In all cases, informed consent and permission was obtained from both parents and/or guardians for the scientific use of the resulting data.

Results

There were 36 cases distributed among 26 (72.22%) males and 10 (27.78%) females. The average age was 9.91 ± 2.37 years (Table 1). 100% of the tests were carried out successfully.

Table 1
Characteristics of the study population

	n
Diagnosis	
Occasional episodic asthma	4 (11.11%)
Frequent episodic asthma	8 (22.22%)
Moderate persistent asthma	20 (55.56%)
OSAHS	4 (11.11%)
Treatment	
GCI in monotherapy	8 (22.22%)
ALT in monotherapy	3 (8.33%)
IGC and long-term adrenergic beta ₂ -agonists	19 (52.77%)
Without treatment	6 (16.66%)

ALT: antileukotriene; IGC: Inhaled glucocorticoids; OSAHS: Obstructive sleep apnoea-hypopnoea syndrome.

Table 2
Readings obtained through plethysmography, with or without closure of the occluder in the study population

sRaw _{TOT} with closure (mean±SD) (kPa/s)	1.37±0.45
sRaw _{TOT} without closure (mean±SD) (kPa/s)	1.37±0.43
sRaw with closure (mean±SD) (kPa/s)	1.21±0.43
sRaw without closure (mean±SD) (kPa/s)	1.21±0.40
sGaw with closure (mean±SD) (kPa/s)	0.91±0.29
sGaw without closure (mean±SD) (kPa/s)	0.90±0.28
RR with closure (mean±SD) (resp/min)	36±2.8
RR without closure (mean±SD) (resp/min)	36.92±2.52

SD: standard deviation; RR: respiratory rate; kPa/s: kilopascals per second; resp/min: respirations per minute; sGaw: specific conductance; sRaw: specific resistance; sRaw_{TOT}: total resistances.

The readings obtained through plethysmography, with or without closure of the occluder, are shown in Table 2. There were no significant differences between the sRaw_{TOT} (0.001 ± 0.09 kPa/s), the sRaw (0.006 ± 0.09 kPa/s) ($p = 0.13$), and the sGaw (0.017 ± 0.08 1/[kPa/s]) ($p = 0.3$), with or without closure of the occluder. There were no significant differences between the regression of the means obtained from sRaw_{TOT}, sRaw and sGaw, with or without closure of the occluder, with respect to the differences between them (Figs. 1 and 2).

There were no statistically significant differences found between the RRs that were measured with or without closure of the occluder (0.88 ± 2.89 resp/min) ($p = 0.1$).

Discussion

Several researchers have published the methodology for determining the sRaw by plethysmography in one single maneuver, at normal breathing rates, without closure of the occluder and without sedation.

Klug et al¹⁰ reported a series of 109 children with sRaw determination by simplified plethysmographic technique with face masks and with an adult accompanying the patient inside the booth, with adjustments performed under BTPS conditions with EC. They described a systematic positive overestimation of 43% in the sRaw with respect to those measured with HRB (heated rebreathing air) (CI 95%=30–70%) with significant and positive dependence on respiratory rate. Its clinical application has shown a significant increase in sRaw in children with asthma and in infants with recurrent wheezing when compared to control groups.^{11,12}

The results of our study are similar to those reported in the literature. There were no significant differences between the regression of the means obtained from sRaw_{TOT}, sRaw and sGaw, with or without closure of the occluder, with respect to the difference between them (Figs. 1 and 2). As a result, there is good agreement between them and both are substitutable, one for the other, in daily clinical practice. This makes it possible to guarantee the determination of total and specific resistance in the airway by means of total body plethysmography without closure of the occluder. In our series, the study population was comprised of children between 6–14 years of age. Therefore the results obtained cannot be directly extrapolated to the preschool population. However, the good agreement obtained in the determination of the sRaw with or without closure of occluder,

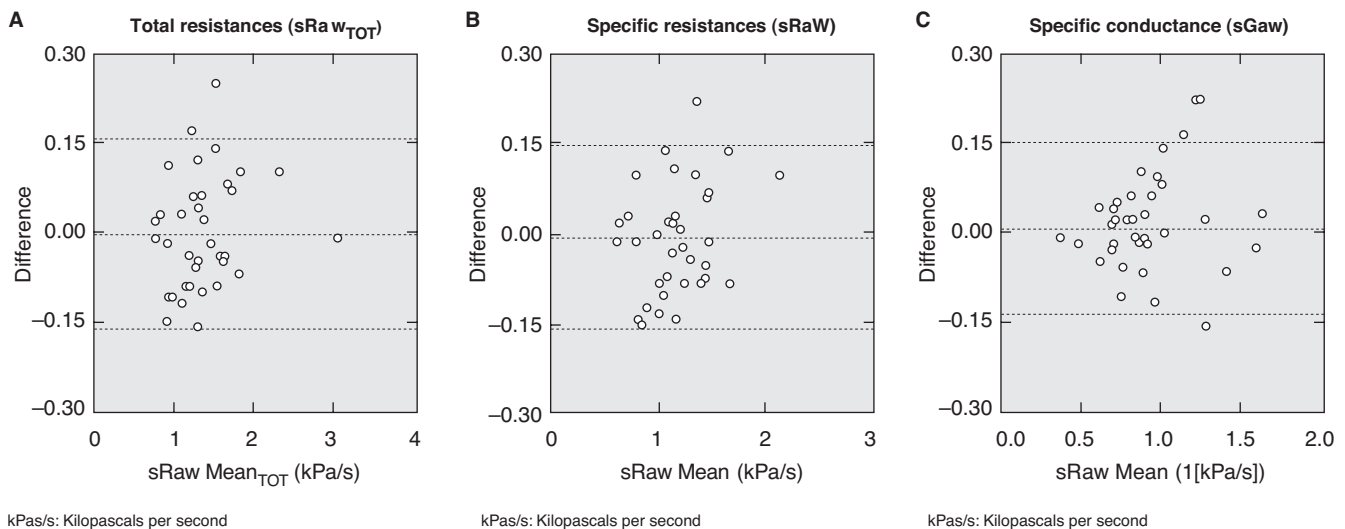


Figure 1. Bland-Altman graphical method. A) There were no differences between the regression of the means of sRaw_{TOT} obtained with or without closure of the occluder with respect to the difference between the same. B) There were no differences between the regression of the means of sRaw obtained with or without closure of the occluder with respect to the difference between the same. C) There were no differences between the regression of the means of sGaw obtained with or without closure of the occluder with respect to the difference between the same.

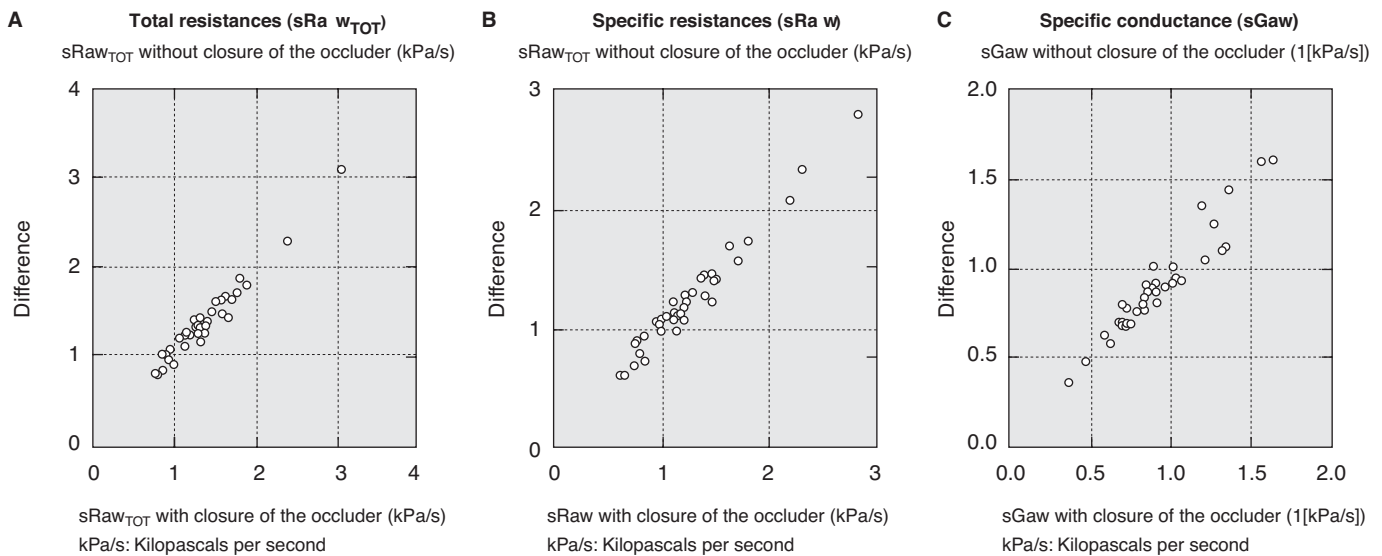


Figure 2. Point diagram (scatter plot): there are no significant differences for the variables (A, B, and C) with and without closure of the occluder.

provides us with the future possibility of determining sRaw by means of plethysmography in young children and in uncooperative children without sedation.

In our series, the diagnosis in 88.89% of the cases was for asthma (moderate persistent asthma 55.56%, episodic asthma 33.33%) and 83% received maintenance treatment, half of them with combination therapy (inhaled glucocorticoids and long-term adrenergic beta₂-agonists) with good control of the disease (Table 1). We cannot assume, and this is a limitation of this study, what the agreement would have been if the cases had had high airway resistances. However, with the validated technique and software used in our series, one can expect that the measurements obtained with or without closure of the occluder, although higher, were equally consistent.

The sRaw is independent of height and sex, which facilitates the longitudinal interpretation of the measurements obtained in the same individual over time.¹³ Its usefulness in the clinical monitoring of chronic diseases (severity of disease and response to treatment) such as asthma and cystic fibrosis and in understanding lung development has been described.^{14,15} It also offers a significant ability to discriminate between healthy and sick. It allows for the measurement of bronchial hyperresponsiveness with a sensitivity (S) of 68%, a specificity (E) of 93%, a positive predictive value (PPV) of 93% and a negative predictive value (NPV) of 69%. It is able to quantify the response to treatment with inhaled glucocorticoids¹⁶ and bronchodilator therapy (S 66%) (E 81%), with a PPV of 84% for a cut-off of 25% decrease in the sRaw (bronchodilation test 9).¹⁷ However, one cannot ignore some limitations in determining sRaw by simplified plethysmographic technique, such as the problems with the correct standardisation of the technique and the variability in the published normal values.

One of the technique's most relevant problems is the patient's breathing pattern, given that an increase in RR means an increase in the flow, which can cause the flow to go from laminar to turbulent. An increase of 50% has been reported in the sRaw due to increases in respiratory rate. Several authors have published the technique's methodology with an approximate recommended RR between 30-45 breaths per minute to avoid the overestimation that depends on the RR when performing adjustments of the measurements under BTPS conditions with EC 9.¹⁰ In our sample, there were no statistically significant differences found between the RR that were measured with or without closure of the occluder

(0.886±2.89 resp/min) (mean difference ±SD), thus removing this confounding factor.

Furthermore, there were discrepancies between the reference values obtained under BTPS and HRB3 conditions and those obtained under BTPS and EC9 conditions. Most researchers recommend obtaining normal parameters for airway resistance in each lung function laboratory.^{3,9}

In summary, the determination of sRaw through simplified plethysmographic technique is not a new technique. However, it is a technique that is rarely used in the routine study of paediatric lung function in Spain, which we believe is due to the lack of familiarity with it. Along with other investigators, we note that it is possible to determine the sRaw through the plethysmographic technique without closure of the occluder, with good agreement with results obtained using plethysmography with closure of the occluder. This technique offers us the future possibility of performing cross-sectional longitudinal population studies, determining sRaw by means of plethysmography in small children and in uncooperative children without sedation and with guarantees.

Conflict of Interest

The authors affirm that they have no conflicts of interest.

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