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ORIGINAL ARTICLE

Impulse oscillometry, spirometry, and passive smoking in healthy children and adolescents

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Abstract
Objective: To identify changes in the forced and quiet breathing parameters of lung function in healthy children and adolescents exposed to passive smoking (PS).
Method: Comparative cross-sectional study. Healthy schoolchildren aged 6 to 14 years. We collected anthropometric data, lung function parameters using spirometry (forced breathing), and quiet breathing parameters using impulse oscillometry. The sample was divided into two groups according to exposure to PS: passive smoking group (PSG) and non-passive smoking group (NPSG). For the statistical analysis, the Shapiro–Wilk test was used to verify data normality and the *T*-test or Mann–Whitney test to compare spirometric and oscillometric parameters between groups ($p \leq 0.05$).
Main findings: The study included 78 children and adolescents, with 14 boys and 25 girls in each group. There were differences in the mean values for peak expiratory flow ($p = 0.01$). There were no significant differences between the groups in values for z-score and lower limit of normal. The PSG had higher mean absolute values for reactance area (X5 = 0.05) and significant percentage of predicted values for the following impulse oscillometry parameters: central airway resistance (R20%, $p = 0.03$) and for the indicators of presence of airway obstruction (Fres%, $p = 0.01$; X5% = 0.01% and AX%, $p = 0.01$).
Conclusion: Children and adolescents exposed to PS had lower values for the spirometric variables and higher values for the oscillometric variables, indicating changes in forced and quiet parameters of lung function compared to the NPSG.

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Introduction

Passive smoking (PS) is defined as the inhalation of cigarette, pipe, or cigar smoke in closed environments.[1] Because the prevalence of respiratory diseases in children is high due to their developing respiratory and immune systems, the repercussions of PS have generated interest in this age range.[2,3]

This condition can be aggravated by prolonged exposure to PS as a result of the parents' smoking habit.[4] These findings are reported in the literature and show that passive exposure to cigarette smoke both in the pre- and postnatal period impairs lung function parameters in children.[5–7] Among the recognized organic effects of PS are immediate or medium- and long-term negative repercussions, particularly decreased lung function, acute infections of the lower respiratory tract, frequent hospital admissions, start and incidence of new cases of asthma, and cancer in adult life.[8–10]

PS can compromise the small airways due to the potential inflammatory reaction caused by the irritating substances found in cigarettes. This event can reduce pulmonary ventilation as a result of increased airway resistance.[7–11] The predisposition to increased airway resistance implies the need for studies with quantitative analysis of forced/quiet breathing of lung function in children and adolescents submitted to PS.

Most studies evaluating the effects of PS on the respiratory tract use spirometry to show reduction in lung flow and volumes.[12–14] One of the disadvantages of this tool is its low sensitivity and specificity to changes in the early stages of chronic respiratory disease and in mild forms of this disease.

The impulse oscillometry system (IOS) is useful in evaluating airway resistance values (from the central area to the periphery) and identifying early changes. The IOS is easy to use, does not require forced expiratory maneuvers, and involves rapid and reproducible measurements requiring minimal cooperation from the subject.[15]

To date, only one study has evaluated the role of IOS and spirometry in healthy adults exposed to PS.[11] Because PS harms children, the evaluation of the respiratory system using spirometry and oscillometry can help to maximize the understanding of the harmful effects of PS and provide strategies in health policies for children and adolescents in countries with a high rate of smokers. This study aimed to identify the changes in the forced and quiet breathing parameters of lung function in healthy children and adolescents exposed to passive smoking (PS).

Method

Type of study

This is an analytical comparative cross-sectional study that included healthy schoolchildren from educational institutions in Florianópolis, SC, Brazil. The study was conducted from October 2012 to May 2014 following approval by the Ethics Committee of the University of the State of Santa Catarina (UDESC) under number 97/2011.

Procedures

The schoolchildren's parents/guardians were informed about the objectives, procedures, risks, and benefits of the study and signed an informed consent form agreeing to their children's participation. They also answered the questionnaire of the International Study of Asthma and Allergies in Childhood (ISAAC) validated for the Portuguese language and a recall interview structured by the researchers.[16]

Healthy schoolchildren of both sexes aged between six and 14 years participated in the study. Participant selection was based on the guidelines of the American Thoracic Society/European Respiratory Society (ATS/ERS).[17] The selected children did not have episodes of wheezing, history of premature birth, respiratory diseases, respiratory tract infection in the previous 15 days, muscular changes, neurological disorders, asthma, or rhinitis, as certified by their ISAAC scores. Regarding the asthma score, we excluded the children aged 6–9 years and 10–14 years with scores $\geq$5 and 6, respectively.[18] Regarding the rhinitis score, we excluded children aged 6–9 years and those aged 10–14 years with scores $\geq$4 and 3, respectively[19] and affirmative answers to question number 2. As for the spirometric criteria, children not exposed to PS should present FEV_1 and FVC $\geq$80%.[20]

In order to select the sample, verify the good health of the participants, and identify the PS, we analyzed the recall interviews for affirmative responses in relation to exposure to PS, the number of smokers in the household, and daily contact time with cigarette smoke. If the parent/guardian answered yes to any of the questions in the interview, the student was included in the group of healthy children exposed to PS (PSG). Children and adolescents were considered passive smokers if one or both of their parents smoked or if there was at least one smoker living in their house[8]. Healthy children and adolescents not exposed to PS were included in the non-passive smoking group (NPSG). Data on smoking during pregnancy was also checked.

For the anthropometric assessment, weight was measured using a digital scale (Ultra Slim W903-Wiso®) and height was measured using a portable stadiometer (Sanny®). Body mass index (BMI) was classified according to the Child growth standards (percentiles BMI for age) of the World Health Organization (WHO) in obese children ($\geq$97th percentile) and underweight children (<3rd percentile).[21] For both groups, children and adolescents with obesity or underweight were not included in the present study.

All participants were subjected to analysis of quiet breathing parameters of lung function using the IOS, according to the ATS/ERS standards for the Forced Oscillation Technique (FOT).[17] The IOS technique is performed as follows: the individual remains in position and is instructed to breathe calmly through a mouthpiece (tidal volume and spontaneously) while wearing a nose clip and the researcher holding the child's cheeks in his hands. To minimize oscillatory pressure loss, the pressure pulse generator transmits brief pressure pulses to the respiratory tract and these are processed.

Frequencies of 5 and 20 Hz were used and the measures considered for analysis were: total airway resistance (R5 resistance to 5 Hz), central airway resistance (R20-resistance to 20 Hz), respiratory impedance (Z5-impedance to 5 Hz), peripheral capacitive reactance (X5-reactance to 5 Hz), reactance curve area below zero (AX), and resonant

frequency (Fres). All participants breathed spontaneously at tidal volume through the machine's nozzle, performing stable breaths. The recording time for data acquisition varied from 20 to 30 s. Three measurements were recorded. A maximum of 10% variation between measurements was allowed for each of the parameters.

Subsequently, spirometry was performed according to ATS/ERS recommendations.[22] The same positioning was adopted for the spirometry test, however, forced expiratory maneuvers were required, in which the child must maximize inspiration followed by rapid, forced, and sustained expiration until the observer orders the interruption. The child was strongly encouraged to make an ''explosive'' effort at the beginning of the maneuver and prolong it for as long as necessary. At least three acceptable and two reproducible curves had to be obtained. Values for *z*-score and lower limit of normal for spirometric parameters were considered. Both tests (spirometry and IOS) were performed using the MasterScreen IOS (Erich Jaeger, Germany). Firstly, the automatic system warm up (15–20 min) was conducted. Next, environmental data were monitored using a thermo hygrometer (Incoterm®), with relative humidity maintained between 40 and 50% and temperature between 17 °C and 40 °C, and these data were input into the system. For the calibration, a 3-l syringe was used, pumping at a uniform and constant rate. The calibration was performed before every evaluation session.

Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences® software (SPSS) 20.0 and presented by descriptive statistics and frequencies, expressed as mean and standard deviation. To compare spirometric and oscillometric data between groups, we used the *T*-test or the Mann–Whitney test, according to the normality of the data verified by the Shapiro–Wilk test. For informative purposes, we presented the data of the predicted values of the oscillometric variables based on the mean height and age of each group for calculation using the second equation proposed by de Assumpção et al.[23] The significance level was set at $p \leq 0.05$.

The sample size calculation was performed considering the variable R5 (kPa/L/s), which represents the total resistance of the respiratory system, and considering data from a pilot study on children and adolescents exposed to smoking, which showed a standard deviation of 0.130 kPa/L/s. For the calculation, the minimum difference to be detected was 0.100 kPa/L/s with 90% power and a 5% two-tailed significance level, which totaled 35 individuals for each group as a sufficient sample. The existence of the variability between the subjects was considered and for this reason the previous sample calculation was made and the reference values for spirometry were used based on the average of the population of this age group.

Results

The study included 78 participants, with 39 allocated to each of the two groups. The sex ratio was the same in both groups (14 boys and 25 girls). The mean age was 9.69 ± 2.31 years in the PSG and 9.92 ± 2.4 years in the NPSG ($p = 0.66$). The anthropometric characteristics are presented in Table 1.

Table 1 Mean and standard deviation of anthropometric characteristics.

	PSG	NPSG	*p*-value
Weight (kg)	35.45 ± 9.86	36.50 ± 11.64	0.81
Height (cm)	139.75 ± 12.79	141.78 ± 16.35	0.54
BMI (kg/m^2)	17.83 ± 2.50	17.64 ± 1.99	0.95

PSG: group with report to passive smoking exposure; NPSG: group without exposure report; BMI (TS): body mass index.

Most of the participants in the PSG lived in households with only one smoker (74.36%), followed by those exposed to two smokers (20.51%). Only one child (2.56%) was exposed to three smokers in the household.

The evaluation of the spirometric data showed that the PSG had lower mean absolute values for all variables. Peak expiratory flow (PEF) showed a difference between the groups ($p = 0.01$) (Table 2). The values for *z*-score and lower limit of normal did not present significant differences between the groups.

Table 3 shows the data obtained using impulse oscillometry for both groups. In the group comparison, the PSG showed significantly higher absolute values for the parameter reactance area (AX) ($p = 0.05$). The PSG also showed higher mean percentage of predicted values for resistance at 20 Hz (R20%), reactance area (AX%), and resonant frequency (Fres%) ($p = 0.03$, $p = 0.01$, and $p = 0.01$, respectively).

Discussion

The present study is the first to use impulse oscillometry with spirometry to compare the effects of PS in healthy children and adolescents exposed and not exposed to PS. Numerous efforts have been reported in the literature to prove the dangers of smoking and PS to the airways, but while the effects of smoking have been widely proven both functionally and pathologically, the repercussions of PS have yet to be determined.

Although most children in the present study were exposed to only one smoker in the household for less than 15 min daily, adverse effects could already be identified. This work found that children and adolescents exposed to smoking had lower absolute values for all spirometric parameters. The PEF value was significantly lower than the values for the children and adolescents with no exposure. All absolute values for the oscillometric parameters were higher in the PSG and this group also showed significant differences in X5, R20%, Fres%, and AX% compared to the NPSG. These data indicate changes in forced and quiet parameters of lung function due to the exposure.

It is known that the toxic and irritant particles in cigarette smoke can cause cellular damage and local inflammation when in contact with the lung's epithelium.[24] Their effects can range from goblet cell hyperplasia, increased mucus production and toxicity in the ciliary epithelium, as well as decreased mucociliary clearance. These events favor the accumulation of secretion in the airways, which leads to a favorable environment for infections. In addition, the

Table 2 Mean and standard deviation of the absolute values, lower limit of normal and *z*-score of predicted value of spirometric variables groups and results of the comparisons.

Spirometric variable	PSG	NPSG	*p*-value
FVC (L)	2.294 ± 0.637	2.510 ± 0.848	0.22
FVC (LLN)	2.145 ± 1.898	1.966 ± 0.638	0.58
FVC (*Z*-score)	0.062 ± 0.953	0.198 ± 1.018	0.61
FEV_1 (L)	2.048 ± 0.606	2.284 ± 0.778	0.14
FEV_1 (LLN)	1.612 ± 0.410	1.722 ± 0.539	0.82
FEV_1 (*Z*-score)	0.143 ± 1.015	0.586 ± 1.052	0.99
PEF (L/s)	4.194 ± 1.278	5.064 ± 1.604	0.01*
PEF (LLN)	0.650 ± 0.175	0.709 ± 0.225	0.31
PEF (*Z*-score)	4.655 ± 0.807	5.277 ± 0.870	0.50
$FEF_{25-75\%}$(L/s)	2.47 ± 0.96	2.966 ± 1.114	0.06
$FEF_{25-75\%}$ (LLN)	1.609 ± 0.410	1.719 ± 0.512	3.98
$FEF_{25-75\%}$ (*Z*-score)	−0.143 ± 1.120	0.487 ± 1.139	0.80
FEV_1/FVC	0.886 ± 0.072	0.905 ± 0.056	0.25
FEV_1/FVC (LLN)	0.777 ± 0.014	0.776 ± 0.016	0.89
FEV_1/FVC (*Z*-score)	0.214 ± 1.252	0.760 ± 1.870	0.25

PSG: group with report of passive smoking exposure; NPSG: group without exposure report; FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; PEF: peak expiratory flow; LLN: lower limit of normal.
* Significance value $p \leq 0.05$ according to the *T*-test and Mann–Whitney test.

Table 3 Mean and standard deviation of absolute values, mean of the predicted values of oscillometric variables for each of the groups according to the average height and age, and the results of the comparisons.

Oscillometric variable	PSG	NPSG	*p*-value
R5 (kPa/L/s)	0.605 ± 0.20	0.512 ± 0.15	0.09
R5%	96.29 ± 22.33	84.07 ± 14.15	0.06
R20 (kPa/L/s)	0.474 ± 0.11	0.425 ± 0.10	0.08
R20%	94.88 ± 17.05	87.09 ± 15.37	0.03*
X5 (kPa/L/s)	−0.168 ± 0.06	−0.153 ± 0.06	0.17
X5%	110.44 ± 34.42	105.94 ± 33.99	0.31
Z5 (kPa/L/s)	0.631 ± 0.21	0.535 ± 0.16	0.08
Z5%	133.72 ± 30.58	127.76 ± 68.66	0.06
Fres (Hz)	17.48 ± 5.52	14.94 ± 4.67	0.07
Fres%	106.68 ± 25.62	93.22 ± 20.99	0.01*
AX (kPa/L)	1.242 ± 1.03	0.759 ± 0.63	0.05*
AX%	136.94 ± 92.10	86.41 ± 56.38	0.01*

%: percentage of predicted; PSG: group with report to passive smoking exposure; NPSG: group without exposure report; R5: resistance at 5 Hz; R20: resistance at 20 Hz; X5: reactance at 5 Hz; Z5: impedance at 5 Hz (all expressed in kPa/L/s); Fres: resonant frequency (expressed in Hz); AX: reactance area expressed in kPa/L).
* Significance value $p \leq 0.05$ according to the Mann Whitney–test.

oxidizing substances present in cigarette smoke, such as oxygen free radicals, cause oxidative damage to the airways, resulting in inflammation and cell death.[25] The combination of these attacks leads to chronic inflammation of the peripheral airways, tissue damage and repair, and secretion stasis, which together can lead to bronchial obstruction.[26]

As there is airway inflammation and obstruction, spirometry has been used to verify the deterioration caused by PS in the respiratory tract, as some studies show.[12,14,27,28] Nuhoglu et al.[12] found lower FEV_1, FEV_1/FVC, and $FEF_{25-75\%}$ for healthy PS children and adolescents between the ages of 6 and 15 when compared to non-exposed children. In contrast, Gilliland et al.[27] obtained similar results to those found in the present study, with lower values for FEF and PEF in PS children. Other studies also demonstrate a reduction in FEF values in children exposed to tobacco smoke.[13,14,28] These results indicate a greater effect of PS on expiratory flows, suggesting effects on the airways and not on lung growth.[13,14]

Although spirometry is widely used for the assessment of lung function, its sensitivity is low and it is difficult to use in children. Only one study shows parameters related to quiet breathing parameters of lung function in adult smokers without chronic diseases.[11] The IOS has been used to detect increased airway resistance and airway obstruction, as seen in children with asthma, and it has been shown to be sensitive in this assessment, which confirms its suitability for this type of analysis.[29–31]

Kalliola et al.[30] assessed the lung function of 105 children using impulse oscillometry and found an increase in R5 in the children exposed to maternal smoking. Kooi et al.[29] found a similar result using the interrupter method (Rint) to assess airway resistance in 557 children. The researchers found significantly higher resistance values for children who had a history of exposure to cigarette smoke. R5 is related to the passage of air through the bronchi and bronchioles, while AX is related to low-frequency reactance that reflects more accurately the peripheral airways. Obstructions can also be assessed by analyzing Fres, a parameter related to the size of the airway.[15]

The study by El-Naggar et al.[11] aimed to determine whether the IOS would be able to detect early airway obstruction and to compare three groups of adults consisting of 20 smokers, 20 former smokers, and 20 controls (non-smokers). Unlike the present study, the authors found no significant differences between groups in the spirometry and oscillometry parameters. Both techniques were equally effective in verifying airway obstruction.

Changes in quiet breathing parameters of lung function in children exposed to PS showed influences of other elements (e.g., anthropometric parameters) on the results. Keskinoglu et al.[32] found higher concentrations of cotinine, a metabolite of nicotine, in younger children and those with higher incidence of lower respiratory tract infection. Similarly, Kooi et al.[29] and Tepper et al.[13] demonstrated increased airway resistance in children with respiratory symptoms and decreased airway resistance in older, taller children.

The impact and intensity of exposure to PS are due mainly to the household smoking habits of parents and directly proportional to the time the child spends with their mother and/or father, the number of cigarettes smoked per day in the household, and whether they are smoked inside or outside the house.[33,34]

Regarding the form of assessment of the exposure to PS, the literature recommends the measurement of cotinine levels as a more reliable method for quantification.[13,32] This biomarker has been shown to be more sensitive than questionnaires used with parents.[32] Questionnaires can provide false answers, compromising the classification of parents as well as the quantification of the effect of exposure outside the home. This fact was observed in the present study, in which some issues related to smoking were omitted by the parents/guardians. This was also one of the limitations of our study. Nevertheless, it is clear that the exposure of healthy children to cigarette smoke was responsible for the decline and loss of forced and quiet breathing parameters of lung function, which corroborates the literature.

The identification of passive smoking through questionnaires has been a useful tool in epidemiological studies to evaluate the harmful actions of active and passive smoking, especially in developing countries where it is difficult to conduct objective tests such as cotinine tests even in a small population. The comparison between lung function parameters with or without exposure to tobacco smoke showed different values and can constitute an epidemiological model of evaluation and provide control measures and information to families of smokers.

The results suggest the need for future studies with a controlled, prospective, and longitudinal design. The inclusion of impulse oscillometry measures has provided new facts about lung function, showing that even slight exposure in children and adolescents can lead to a significant risk of airway obstruction.

Conclusion

The findings of this study showed that healthy children and adolescents exposed to PS presented changes in the forced breathing parameters of lung function, such as PEF. Furthermore, the IOS proved to be able to identify early changes in quiet breathing parameters of lung function due to exposure to PS related to the important indicators of the presence of peripheral and central airway obstruction.

Ethical disclosures

Protection of human and animal subjects. The authors declare that no experiments were performed on humans or animals for this study.

Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent. The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author is in possession of this document.

Conflicts of interest

The authors have no conflicts of interest to declare.

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