Feasibility of structured light plethysmography for the evaluation of lung function in preschool children with asthma

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ABSTRACT

Background: *Structured light plethysmography (SLP) is a new noninvasive technology to capture the movement of the thoracic and abdominal wall, and to assess some parameters indicative for lung function.*

Objective: *The purpose of the study was to evaluate the feasibility of SLP in children with asthma.*

Methods: *A total of 52 patients were enrolled: 25 with asthma exacerbation (group 1), 13 with well-controlled asthma (group 2), and 14 healthy controls (group 3). Every patient underwent SLP evaluation and a lung function test.*

Results: *SLP evaluations showed that the ratio of inspiratory flow at 50% of tidal volume (Vt) to expiratory flow at 50% of Vt, in which Vt is taken to be the exhaled chest wall movement, and flow is taken to be the time derivative of the chest wall movement (IE50) value increased in group 1 compared with groups 2 and 3, with statistical significance ($p = 0.018$); the data were consistent with the spirometry parameter. A correlation between the IE50 and forced expiratory volume in the first second of expiration was highlighted ($r = -0.35$, $p = 0.019$).*

Conclusion: *SLP assessed airway obstruction, and its use in clinical practice could be applied in preschool children in future studies.*

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Structured light plethysmography (SLP) is a new noninvasive technology to capture and measure the movement of the thoracic and abdominal wall, and to produce real-time data on changes during tidal breathing. A grid of light is projected from a light projector onto the chest and abdomen anterior wall of an individual.[1] Movements of the grid are viewed by two digital cameras located in the scanning head and then processed to reproduce a three-dimensional (3D) model, and to assess parameters indicative for lung function. SLP also allows evaluation of the differences in the contribution to respiratory movements between two different regions, *e.g.*, the thoracic and abdomen wall or the right and left side of the thoracic wall, data not derivable with traditional lung function tests.[2]

The first mathematical models to extract lung function parameters from the thoracic wall movement were proposed by Konno and Mead,[3] and optoelectronic plethysmography is an example of technology based on evaluation of movements of the thorax. Measurements of respiratory movement by infrared cameras can provide volumes and information regarding chest wall mechanics. This Respiratory movements has been used to estimate the chest wall mechanics during tidal volume (V_t) and different health conditions and situations.[4] Spirometry is the most useful and routinely used test for the evaluation of common pediatric obstructive lung diseases, *e.g.*, asthma. Production of reliable spirometry results requires coaching from the clinician and both coordination and the child's cooperation; in fact, spirometry is not usually obtainable in children who are <6 years old. The major parameter to follow is the duration of the expiratory maneuver, which is variable at young ages but should always exceed 1 second and plateau for reliable interpretation.[5] SLP is simple to use, does not require particular cooperation, and direct contact with the patient; indeed, there is no risk of cross-infection; these characteristics make it feasible to use in children.[6] At this moment, few data are available in children. The purpose of the study was to evaluate the feasibility of SLP in children, particularly among preschool children.

METHODS

Subjects

The study was conducted in the Pediatric Section of the University Hospital of Verona between September 2014 and March 2015. Patients, age range 3–16 years,

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referred to our department for asthma or growth checkup were eligible. Asthma was diagnosed according to the American Thoracic Society criteria.[7] Asthma control was assessed by following the recent Global Initiative for Asthma (GINA) guidelines,[8] and exacerbation was defined according to GINA guidelines criteria. We categorized the patients into three groups: group 1, those with recent asthma exacerbation after clinical stabilization and without respiratory distress during the test time; group 2, those with well-controlled asthma; and group 3, patients referred for growth checkup, considered as the healthy controls. Every patient enrolled completed an anamnestic schedule, underwent clinical examination, and performed SLP evaluation and spirometry when it was possible to achieve an acceptable result. All investigations were carried out with fully informed written parental consent. The study was approved by the ethical committee of Verona (code CESC813).

Spirometry

Spirometry was performed by using an electronic spirometry (Viasys Masterscope CT, Jaeger, Hochberg, Germany) calibrated with a 3-L syringe (Jaeger) before the arrival of the subjects, and the ambient temperature and humidity were recorded. The test was performed with the child standing and wearing a nose clip. All the subjects were instructed to avoid the use of short-acting bronchodilators at least 6 hours before the visit. Normal forced expiratory volume in the first second of expiration (FEV_1) was defined as ≥80% predicted in accordance with European Respiratory Society/American Thoracic Society guidelines.[5] Spirometry was performed before and 15 minutes after the administration of 400 μg of salbutamol through a pediatric spacer. The bronchodilator reversibility test result was defined as positive if there was a change in FEV_1 of ≥12%.[5]

SLP

With SLP, when using a Thora-3Di (Pneumacare Ltd., Cambridge, U.K.), the patients wore a tight white T-shirt, were lying on the bed, and were breathing at Vt during the examination. The examination took a minimum of 2 minutes, during which the only cooperation asked of the patient was to avoid movements. It was suggested to the children to simulate sleeping to be able to achieve good results. The grid pattern projected was aligned with the center of the thoracoabdominal wall. No calibration is required for measurements of tidal breathing parameters of SLP; however, for this study, the SLP was calibrated according to the manufacturer (Pneumaview-3D, Pneumacare Ltd., Cambridge, U.K.). The software is able to calculate, through of breath detection algorithm, the respiratory displacements and provides the respiratory parameters: respiratory rate, breath cycle timings (inspiratory time, expiratory time, and total breath cycle time), and the ratio of inspiratory to expiratory flow at 50% of tidal volume, in which Vt is taken to be the exhaled chest wall movement, and flow is taken to be the time-derivative of the chest wall movement (IE50). The same operator performed all tests on all the patients (MP).

An increased value of IE50 is suggestive of expiratory flow limitation. The "principal angle" is the angle of the principal axis of the Konno-Mead plot relative to the 45° line. Principal angle provides information similar to the "relative expired contribution," the ratio of a region's expired movement change (exhalation) to the Vt, when Vt is taken to be the total exhaled chest wall change. "Spread" is the ratio of the length of the secondary axis to the length of the principal axis and provides information such as the "phase angle," a value of synchronicity between two regions, measured in degrees; a phase of 180 means one region moves in exactly the opposite direction to the other region.

Statistical Analysis

The distribution of the data was examined, and nonparametric tests were applied as appropriate. A comparison between the two groups was made by using the Mann-Whitney test. Comparisons of more than two groups were made by using the Kruskal-Wallis test, followed by the Mann-Whitney test if a significant difference was found. The Bonferroni correction was used for multiple comparisons. The Spearman rank correlation was used to look for associations. A p value of ≤0.05 was considered statistically significant.

RESULTS

A total of 52 patients were enrolled in this study. Twenty-five patients were affected by asthma exacerbation (group 1), with a median age of 7.95 years (interquartile range [IQR], 4.81–9.38); among them, 50% were already under treatment for asthma. We also enrolled 13 patients in group 2, who had been referred to our unit for asthma follow-up: all showed well-controlled asthma, with median age 9.93 years (IQR, 6.46–13.76 years). We wanted to test the ability of the SLP to highlight different degrees of bronchial obstruction, so we also enrolled healthy controls into group 3; 14 patients, with a median age of 10 years (IQR, 8.5–12.00 years). Ten children <6 years old were included in the study: eight in group 1 and two in group 2. There was no statistical significance different among these groups; complete demographic data are shown in Table 1. All the patients were able to undergo SLP evaluation, even the preschool age children; however, only 76.9% (40 patients) were able to perform a valid spirometry test. The children in group 1 had spirometry parameters (forced vital capacity, forced expitatory

Table 1 **Characteristics of the patients***

	Group 1#	Group 2§	Group 3¶
Age, y	7.95 (4.81–9.38)	9.93 (6.46–13.76)	10.00 (8.5–12.00)
Height, cm	129.00 (117.50–141.25)	149.00 (127.5–160.50)	139.65 (119.00–155.50)
Weight, kg	24.95 (18.50–35.23)	44.00 (33.00–60.75)	34.75 (22.75–47.70)
Body mass index, kg/m^2	15.75 (15.20–18.40)	19.70 (18.70–26.03)	17.18 (15.51–21.42)

**All data are median (interquartile range).*
#Patients with asthma exacerbation.
§Patients with well-controlled asthma.
¶Patients referred for growth checkup, considered the healthy controls.

Table 2 **Spirometry parameters***

	Group 1#	Group 2§	Group 3¶
FVC%	73.30 (65.35–88.45)	111.35 (104.30–116.75)	104.60 (97.00–111.28)
FEV_1%	80.4 (65.03–88.83)	105.75 (102.38–111.08)	111.60 (99.13–120.00)
PEF%	76.90 (64.10–90.20)	96.40 (80.22–117.73)	93.65 (88.05–103.93)
MMEF%	44.30 (23.15–64.60)	75.20 (65.23–112.10)	98.55 (78.10–107.88)

FVC% = forced vital capacity; FEV_1% = percentage forced expiratory volume in the first second of expiration; PEF% = peak expiratory flow; MMEF% = maximal midexpiratory flow.
**All data are median (interquartile range).*
#Patients with asthma exacerbation.
§Patients with well-controlled asthma.
¶Patients referred for growth checkup, considered the healthy controls.

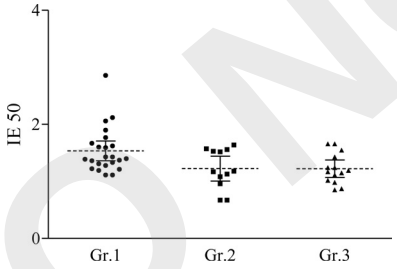

Figure 1. *IE50 median value in the three different groups of patients. Group 1 (Gr. 1) is of patients with asthma exacerbation; group 2 (Gr. 2), patients with well-controlled asthma; and group 3 (Gr. 3), patients referred for growth checkup, considered as the healthy controls. Gr. 1 showed an increased value of IE50.*

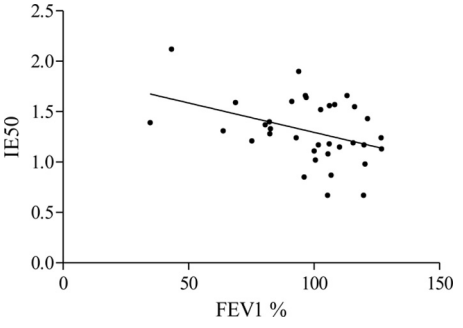

Figure 2. *Correlation between FEV_1 and IE50 in patients who underwent SLP and spirometry.*

volume at first second, peak expiratory flow, maximal midexpiratory flow$_{75–25}$) lower than the children in groups 2 and 3 ($p < 0.001$), as expected. No difference was found between groups 2 and 3 (Table 2). SLP evaluations showed that the IE50 increased, with statistical significance ($p = 0.018$), in group 1 compared with groups 2 and 3 (Fig. 1). A weak correlation between the IE50 and FEV_1% predicted values was found ($r = -0.35$; $p = 0.019$) (Fig. 2).

DISCUSSION

The first technology to provide direct measurements (both absolute and variations) of the volume of the chest wall and its compartments was optoelectronic plethysmography (OEP). OEP measurement is noninvasive and does not require calibration or the cooperation of the subject. OEP can be used without a mouthpiece and nose clip, in different postures, in different conditions (rest, physical exercise, sleep), and with several clinical conditions such as COPD (chronic obstructive pulmonary disease), asthma and neuromuscolar disease.[9] Gorini *et al.*[10] assessed the degree of hyperinflation associated with acute bronchoconstriction by using OEP. OEP has been reported as a technique to evaluate chest wall asynchrony after lung volume reduction techniques in selected patients with emphy-

sema,[11] and provides information how the abdominal contents in supine posture cause changes in lung volume and lung capacity.[12] Layton *et al.*[13] compared simultaneous Vt by using OEP and spirometry during a maximal cycling exercise. The Vt measurements during exercise by using OEP and spirometry were closely correlated, and the difference between measurements was not significant.

SLP is a new method to evaluate chest and abdomen wall movement, and to obtain parameters about the respiratory pattern, movements, and asynchrony. The first analysis of chest wall movement and volume change to extrapolate lung function parameters were performed by Konno and Mead.[3] The feasibility of the examination in children represented the primary outcome of our study. In our study, SLP has been performed successfully in our study, including in preschool children. Indeed, SLP does not require patient cooperation and there is no direct contact, therefore, no risk for infections. Moreover, SLP does not require nose clips or a face mask, which may modify the pattern of breathing, and allows the subject to be free to breathe normally for a few minutes. The child lying on the bed breathing with Vt, while the operator (MP) adjust the grid-light in the correct position in thoraco abdominal region. After grid positioning, the software starts recording the respiratory movements for 2 minutes. Simplicity application of SLP, the short time recording are well acceptable also in preschool children when perform reliable test is usually difficult. Nevertheless, application of this new technology in our pediatric population confirmed the possibility to study the airway obstruction and then differentiate children with controlled and uncontrolled asthma, as previously reported in a study by Hmeidi.[14]

Although there are no values in the literature of normality in the pediatric population at this time, SLP adds many advantages in the study of lung function:

- It provides an indirect computation of volume changes without the patient having to use a mouthpiece, which may alter the normal breathing pattern[15]; it is noninvasive; and it does not require contact with the patient and, therefore, no risk of infection.
- It does not require the cooperation of the patient, and it is available for preschool children, as established in this study, but it could also be useful in those in whom it is difficult to obtain a reliable pulmonary function test.
- It provides information about movements of the different compartments of the thoracoabdominal wall and of the two halves (left and right); these data are not extrapolated by traditional lung function tests.

The measurement of lung function is frequently performed by using spirometers or pneumotachometers; and, although considered a criterion standard, these measurement tools are associated with different limitations, mainly (a) variations in temperature and humidity, barometric pressure, and viscosity and density of exhaled gases, which can influence measurement; and (b) they cannot be used for evaluation of children who are uncooperative.

According to the GINA guidelines,[8] spirometry, including baseline FEV_1 and the bronchodilator response to short-acting β-agonists should be performed in children as objective measures to establish the diagnosis and severity of bronchial asthma. Spirometry requires time and trained personnel conducting pulmonary function tests as recommended by American Thoracic Society.[16] Although spirometry is considered to be the criterion standard for pulmonary function testing, it has problems in meeting quality control standards, especially in preschool children.[17] Even though there are reports in the literature of spirometry successfully undertaken in preschool children, success rates vary from study to study.[18] In a recent study among 200 subjects, mean $\pm$ standard deviation age of 4.0 ± 0.7 years, the number of acceptable efforts correlated with age ($r = 0.29$; $p < 0.001$): from 45% among 3-year-old children to 87% among 5-year-old children.[19] Due to the difficulty of performing spirometry with preschool children, other techniques, *e.g.,* the impulse oscillometry system (IOS), were developed. IOS is a sensitive rapid technique that only requires passive patient cooperation. Data are available on bronchodilation tests that used the IOS in children with asthma who were <6 years of age.[20] However, IOS and interrupted technique (Rint) can evaluate airway resistances that are indirect measure of lung function.[21]

SLP showed increased values of the IE50, as an index of airway obstruction among children with asthma exacerbation. The IE50 in this group was larger than in this group IE50 is statistically higher than well-controlled asthma and healthy controls. These data were consistent with spirometric findings. Indeed, the IE50 had an inverse correlation with FEV_1, the criterion standard to diagnose airway obstruction; therefore, there are indications that IE50 is related to airway obstruction, as reported in previous study.[1] Also, in a study performed in adults who were affected by chronic obstructive pulmonary disease[2,22] and in an adolescent with pneumonia,[23] the IE50 was found to be larger compared with a healthy subject. We need further studies to confirm a good correlation between these two parameters in children with asthma.

Strengths and Weaknesses of the Study

The strengths of the study were represented by the first-time comparison between the pulmonary function

test and the application of the SLP in preschool children during the same medical examination. Previous studies describe the SLP in adults[22] or in children >7 years.[6] Although the SLP technique does not measure flows or volumes, the displacement of the chest wall offers a noninvasive methodology that can provide useful information about airway obstruction and mechanics, during tidal breathing, without requiring forced breathing maneuvers to evaluate. Moreover, smalls groups representative of the pediatric age able to perform a lung function test were homogeneity, and the same operators performed SLP and spirometry.

The main weakness of the study is that detecting clinical meaningful differences are limited with SLP at the present time. Another possible limitation may be the sensitivity to minimal movements. In this regard to the purposed to set the registration time in only 2 minutes to limit the lack of cooperation (avoiding body movements), especially in younger patients. Furthermore, we did not study the variations of the IE50 after bronchodilator, even if previous studies describe these data in children.[13,14]

CONCLUSION

SLP is a useful new noninvasive technology to assess lung function. It does not require the cooperation of the child, therefore, it is also feasible to use with preschool children. The IE50 is able to assess airway obstruction because it has shown correlation with FEV_1 at spirometric tests. We need further studies to obtain normality data in children and to confirm these data. In future studies, the SLP could be applied in different conditions that affect lung function in children.

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