Respiratory and thoracoabdominal motion pattern at rest and after sub-maximum effort in children with asthma

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ABSTRACT

Asthma involves an increase in airway resistance even in periods between attacks, which generates changes in thoracoabdominal kinematics. The aim of the present study was to detect these adaptations at rest and after physical effort. Evaluations were performed using optoelectronic plethysmography at rest and immediately after physical effort of moderate intensity. Thirty-two children and adolescents participated in the present study (16 asthma- AG and 16 health controls-CG). After exercise, the AG exhibited a less variability of respiratory variables. The kinematic behavior of thoracoabdominal motion was the inverse of that found in healthy controls. These findings suggest mechanical and physiological adaptations to minimize the possible turbulence of the airflow and reduce the impact of airway resistance during physical exertion. Moreover, these changes are found even at rest and in patients whose asthma is clinically controlled.

1. Introduction

Respiratory pattern is the manner that breathing occurs most of the time and involves neuromuscular mechanisms. One’s respiratory pattern undergoes changes in the occurrence of strong emotions, such as fear or anxiety, physiopathological conditions, as well as due to an increase in demand, as occurs during physical exertion (Ramonatxo et al., 1989). Such changes are an attempt to meet the needs of the organism, leading to the adoption of a pattern that is more suitable to the acute or chronic demand (Ceugniet et al., 1996).

Respiratory dynamics is complex and involves not only neural control but also motion of the thoracic and abdominal compartments. The motion pattern of these compartments is associated with respiratory efficiency and should occur to meet demands with the least possible energy expenditure. In situations of an increase in the resistive component, as occurs in asthma, both neural control and motion patterns are altered in comparison to what occurs in healthy individuals with no mechanical impairment (Seddon, 2015; Gautier and Denjean, 2005).

Asthma is a chronic condition with periods of exacerbation. Even in periods between attacks, asthmatic individuals have a certain degree of respiratory resistance related to the severity of the disease. These dynamic changes in respiration have been studied for decades during an attack (Asai et al., 1990) or in situations of different intensities of exertion, such as physical activity (Ramonatxo et al., 1989). Studies involving asthmatic children have evaluated the respiratory pattern, but there is a lack of information in the literature on the thoracoabdominal motion pattern with different levels of physical exertion, especially sub-maximum levels, at which the majority of daily activities are performed.

The analysis of thoracoabdominal motion enables the determination of the integrated function of the respiratory muscles (Gaultier and Denjean, 2005). Moreover, the clinical evaluation of the respiratory pattern and thoracoabdominal motion during sub-maximum exercise can be valuable for the identification of the respiratory mechanics of children with asthma and could subsequently serve as a parameter for assessing the effectiveness of interventions administered to this population (Neder et al., 2003).

Therefore, the aim of the present study was to evaluate the respiratory and thoracoabdominal motion pattern in children and adolescents with asthma at rest and following sub-maximum physical exertion.
2. Materials and methods

2.1. Type of study

A cross-sectional study was conducted involving the evaluation of the thoracoabdominal motion pattern before and after sub-maximum physical effort in asthmatic and healthy children and adolescents.

2.2. Ethical aspects

This study was conducted in accordance with the norms for research involving human subjects stipulated in Resolution 466/2012 of the Brazilian National Board of Health and received approval from the Human Research Ethics Committee of Nove de Julho University (certificate number: 3.522.595/2019).

2.3. Setting and sample

This study was developed at the Multidisciplinary Movement Lab (optoelectronic plethysmography module [OEP]) located on Memorial da América Latina Campus of Nove de Julho University (UNINOVE) on Av. Francisco Matarazzo, 376, Barra Funda, São Paulo, SP, Brazil. The participants were sent from the UNINOVE physical therapy clinics and controls were siblings, family and friends of children in the asthma group.

2.4. Inclusion criteria

Male and female children and adolescents five to 14 years of age with a diagnosis of asthma (GINA (Website., 2018)) and healthy controls in the same age range were included in the present study. The participants did not practice regular physical activity. Those in the asthma group (AG) needed to have gone without an attack for at least 30 days. All volunteers agreed to participate and their legal guardians signed a statement of informed consent.

2.5. Exclusion criteria

The exclusion criteria were the impossibility to understand any of the tests, intolerance to the proposed activities, an active infectious process with fever, heart disease, and not being followed up by a pneumologist.

3. Evaluations and tests

3.1. Evaluation of thoracoabdominal motion using OEP

Data collection was performed using an optoelectronic plethysmograph (OEP) (BTS system, Italy), equipped with eight cameras (four positioned in front and four positioned behind the subject) for the capture of thoracoabdominal motion with the aid of 89 fluorescent markers attached to the thorax. The cameras were synchronized with axial diodes that emitted infrared light reflected by the markers. Thoracoabdominal movements were transmitted in real time at 60 frames per second to the OEP Capture software and analyzed using the Smart Analyzer software, which transformed the data into three-dimensional (3D) geometric information and calculated the data on pulmonary mechanics and thoracoabdominal kinematics.

For accurate 3D reconstruction, the cameras were adjusted and a relatively simple calibration of the equipment was performed. The reflective markers were attached with double-side adhesive to the thorax of the participants (Fig. 1), who remained seated on a stool in a position predetermined by the models found in the software of the equipment. The markers were placed on anatomic structures from the sternum and clavicles to the anteroposterior iliac crests. A total of 89 markers were placed (42 anterior, 37 posterior, and 10 lateral).

The OEP readings were performed with the child breathing spontaneously before and after physical effort. During the reading, the participant was instructed to remain seated with hips and knees 90°, feet supported on the floor, and hands supported on the waist such that the arms did not interfere with the capture of any marker by the cameras (Fig. 2). The volunteer was instructed to breathe normally. The movements of the thorax and abdomen were captured for 50 s (mean of 20 respiratory cycles per reading). Subsequently, the three most homogeneous and technically adequate (size and height) cycles were selected for analysis.

The following were the OEP variables: minute volume, tidal volume (TV), inspiratory time (Ti), expiratory time (Te), total cycle time (Tot), thoracic TV, % thoracic TV, thoracoabdominal compartment TV and % TV thoracoabdominal compartment (compartment situated between the thoracic and abdomen), TV abdomen and %TV abdomen; variations in abdomen volume (VAb) and pulmonary rib cage (RCp) divided by Ti were used as contraction velocity indices of the diaphragm (VAb/Ti) and rib cage (VRCp/Ti), respectively; the variation in abdomen volume divided by the expiratory time (VAb/Te) was used as the contraction velocity index of the abdominal expiratory muscles, as described elsewhere (Alliverti, 2008).

The markers enabled capturing the rib cage motion by the cameras and determining the movements of the different compartments with the aid of the Smart Capture software. For the present study, three compartments were considered: thoracic compartment, thoracoabdominal compartment, and abdomen. In the analysis of plethysmography, the anatomical thoracic compartment is subdivided into thoracic and thoracoabdominal or intermediate, it is considered a point of lower mobility. This subdivision is not anatomical only considered for kinematic analysis. The compartments that move with greater amplitude are the thoracic and abdominal, which characterize the breathing pattern. As the respiratory movements were performed, the markers enabled the generation of reports per compartment through derivations and 3D geometric compositions.

3.2. Step exercise

Physical activity was performed with a step measuring 20 cm in height for 3 min and paced with the aid of a metronome so that the child reached 60–70% maximum heart rate (Tanaka) (Gorini et al., 1999). The aim of the activity was to enable the evaluation of the thoracoabdominal motion pattern before and after sub-maximum effort. This intensity was selected to minimize the possibility of induced bronchospasm.

3.3. Lung function test

The lung function test is used to characterize the severity of asthma and depends on factors such as weight, height, sex, age, smoking, and ethnicity. The interpretation is based on reference values calculated for a healthy population. This exam is used to detect the limitation of expiratory airflow, determining the diagnosis of asthma based on a reduction in forced expiratory volume in the first second (FEV1) to less than 80% of the predicted value and the ratio between forced vital capacity (FVC) and FEV1 (FEV1/FVC) less than 80% in pediatric patients (Jones et al., 2020).

3.4. Asthma control questionnaire

The Asthma Control Questionnaire (ACQ6) is used to evaluate the clinical control of asthma and is composed of seven questions: five
addressing the symptoms of asthma, one on the use of a short-lasting β2 agonist as a rescue medication, and one on the pre-inhaler FEV1 in percentage of the predicted value. The score is the mean of these items and ranges from 0 (completely controlled) to 6 (uncontrolled) using a seven-day period as reference. The cutoff point for controlled/uncontrolled asthma is 2 points. The participants were classified as having controlled (<0.75), partially controlled (0.75–1.5), or uncontrolled (>1.5) asthma. A difference of 0.5 points on a seven-point scale is considered the minimum clinically important difference (Juniper et al., 2005).

3.5. Sample size calculation and statistical treatment

The sample size was calculated based on a pilot study conducted with 10 individuals, considering a standard deviation of 0.4 with an alpha of 0.05, power of 80% and a difference to be detected in the expiratory time of 0.3 s, the minimum sample is 29. The decision was made to evaluate a minimum of 32 individuals.

The Shapiro-Wilk test was used to determine the normality of the data. For comparison between the groups in two moments as in the characterization of the samples, the unpaired t-test was used. Statistical analysis was performed using SPSS and repeated measures ANOVA test was performed with post-Hoc Bonferroni for the analysis of optoelectronic plethysmography. The variables are expressed as means and SD. Statistical significance was considered p < 0.05.

| Table 1 |
|----------------|------------------------|-------|
| Characteristics of sample. |
| A) Anterior; B) Posterior; C) Lateral. |

BMI-body mass index; FTV (%)—forced total volume; FEV1 (%)—Forced expiratory volume in first second; ACQ6—Asthma control questionnaire. Unpaired t-test *p < 0.05.
4. Results

Thirty-two children and adolescents were analyzed (16 in the AG and 16 in the CG). Table 1 displays the data on the anthropometric characteristics, lung function, and clinical control of asthma (ACQ6). The sample was mainly composed of children and adolescents in the ideal weight range and those in the AG had clinically controlled mild to moderate asthma.

Resting heart rate (HR) in the AG was higher than that in the CG, but the difference did not achieve statistical significance. The mean number of steps was similar in both groups and intensity achieved during the physical exercise was 60–70% of maximum HR in both groups. FEV1 did not show a variation greater than or equal to 10% suggestive of exercise-induced bronchospasm. Significant differences in FEV1 were found between groups both before and after exertion (Table 2).

Regarding the respiratory pattern and thoracoabdominal motion evaluated using OEP, the changes in minute volume, respiratory rate, and tidal volume (TV) were greater in the CG after exertion (Table 3). The thoracic contribution to TV at rest was greater in the AG. After exertion, this contribution tended to reduce by 2.7%. The opposite occurred in the CG, with an approximate 7% increase in the contribution of the thoracic compartment after effort. In contrast, the contribution of the abdominal compartment to TV was greater at rest in the CG and tended to reduce by 7.8% after physical exertion. The opposite occurred in the AG, with a 2.2% increase in the participation of the abdominal compartment following physical exertion.

There was an increase in the velocity of contraction of the diaphragm, abdominal respiratory muscles and rib cage muscles in both groups evaluated by the volume of the abdomen divided by the expiratory time (Vab/Te), abdomen tidal volume divided by inspiratory time (Vab/Ti) and rib cage tidal volume divided by Ti (VRCp/Ti), however, this increase was significant only in the CG (Table 3).

5. Discussion

Based on the present findings, the contribution of the thoracic compartment to tidal volume is greater in asthmatic children and adolescents, whereas the contribution of the abdominal compartment is greater in healthy children and adolescents. The motion pattern of the thoracoabdominal complex during quiet breathing and following physical exertion as well as in patients with diseases has been studied for decades, but data on the pediatric population with asthma following sub-maximum exercise are scarce (Troyer et al., 1984; Campbell, 1958; Kenyon et al., 1997). The present findings offer important information that asthmatic children/adolescents have kinematic differences that affect the coordination of respiratory muscle action even at rest and during moderate levels of effort when the disease is clinically controlled and that these differences are likely to interfere in the performance of physical and cognitive (non-respiratory) activities (Fokkema et al., 2006).

For greater efficiency and lower energy expenditure during normal respiration at rest, there is synergic action between the primary motor muscles that act in a phasic manner and respiratory accessory muscle that act in a tonic manner to stabilize the rib cage. This synergic action is seen in the motion of the thoracic and abdominal compartments, which must move in phase (together) upward and outward in the inspiratory phase as well as inward and downward in the expiratory phase (Troyer et al., 1984; Campbell, 1958; Kenyon et al., 1997). Under conditions of an increase in demand due to physical exertion, it is normal for the thoracic compartment to have greater participation (as found in the present study), with greater expansion generating an increase in minute volume and tidal volume due to the greater length and motion-generating capacity of the accessory muscles (Ratnovsky et al., 2008).

In the presence of chronic bronchial obstruction, as occurs in asthma, the inspiratory muscles work against an increase load even at rest, generating an altered biomechanical arrangement and asynchrony between the primary respiratory muscles and accessory muscles. The accessory muscles enter into action when the body is at rest or when the level of exertion is low and the forces of this muscle group, which work in an additive way under normal conditions, begin to work in a dispersive manner. The result is an early elevation of the thoracic compartment, a shorter muscle length, and limited relaxation. Moreover, abdominal tension occurs in the inspiratory phase in asthmatic children, whereas maximum tension occurs in the expiratory phase in healthy children (Fokkema et al., 2006).

When there is an increase in demand, the participation of the thoracic compartment is reduced in asthmatic children and adolescents, even during sub-maximum activities (as demonstrated herein). This justifies the small increase found in abdominal participation, as the shortening of the inspiratory muscles limits the longitudinal movement of the diaphragm (Asai et al., 1990; Aliverti, 2008; Ratnovsky et al., 2008).

Tidal volume, inspiratory time, and expiratory time at rest were higher in children and adolescents with asthma compared to healthy controls and the changes in tidal volume, minute volume, and respiratory rate following physical exertion were smaller. These findings are in agreement with data reported by Ramonatxo et al.,1 who also found such a respiratory pattern (longer inspiratory and total times, greater tidal volume, and smaller change in respiratory rate). The authors attributed the lower level of physical effort in asthmatic children to the difficulty in increasing the respiratory rate. The respiratory pattern adopted due to the limitations imposed by airway resistance is slower in the attempt to swirl the air less. The longer inspiratory time in these children and adolescents both at rest and during physical effort denotes greater respiratory work, which demonstrates the cost of these biomechanical arrangements adopted for the maintenance of normal ventilation (Ramonatxo et al., 1989; Fokkema et al., 2006).

The contraction velocity of the muscles that participate in breathing tends to increase with the ventilatory demand, however in children with asthma, due to this new adaptive biomechanical arrangement, the contraction velocity does not increase significantly, as this would increase the airflow velocity and would have a negative impact on resistance in both the inspiratory and expiratory phases, which may contribute to the appearance of dynamic hyperinflation. This is a gap that still needs to be elucidated and may explain part of the lower resistance to physical exertion in patients with asthma (Ratnovsky et al., 2008).

A limitation that could be attributed to the present study is the non-use of electromyography. However, these respiratory patterns and muscle activations are widely described in the literature. What the present investigation offers as innovating is that these behaviors emerge even during sub-maximum levels of effort in patients whose asthma is clinically controlled and seem to depend little on the severity of the

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Table 2

| Characteristics of exercise | Asthma (n = 16) | Control (n = 16) | p     |
|-----------------------------|----------------|----------------|-------|
| HR rest (bpm)               | 111 ± 21       | 98 ± 16        | 0.06  |
| Maximum HR (bpm)            | 134 ± 16       | 141 ± 33       | 0.54  |
| % of max HR                 | 66.6 ± 8.5     | 66.5 ± 14.5    | 0.976 |
| Steps in 3 min (TS3)        | 80.9 ± 11.7    | 83.5 ± 9.2     | 0.495 |
| Before TS3 SpO2 (%)         | 95.1 ± 3       | 95 ± 2.8       | 0.293 |
| After TS3 SpO2 (%)          | 95.8 ± 2.6     | 95.5 ± 2.8     | 0.216 |
| Before TS3 FEV1 (L)         | 1.8 ± 0.5      | 2.1 ± 0.9      | 0.201 |
| After TS3 FEV1 (L)          | 1.7 ± 0.5      | 2.2 ± 0.9      | 0.04* |
| Before TS3 FEV1 (%)         | 85.7 ± 10      | 101 ± 15       | 0.002*|
| After TS3 FEV1 (%)          | 80.9 ± 11      | 104.7 ± 12     | 0.006*|

TS3: Three minutes step test, HR: heart rate, SpO2: peripheral oxygen saturation, FEV1 (%)-Forced expiratory volume in first second percentage of expected value. A significant difference (’p < 0.05), was found in FEV1 between the initial (before physical exertion) and final (after physical exertion) groups. Unpaired T Test *p < 0.05.
children and adolescents at rest and after sub-maximum effort was the interest or personal relationships that could have appeared to influence Declaration of competing interest

The kinematic behavior of thoracoabdominal motion in asthmatic children and adolescents at rest and after sub-maximum effort was the inverse of that found in healthy controls. These findings suggest mechanical and physiological adaptations to minimize the possible swirling of the airflow and reduce the impact of airway resistance during physical exertion. Moreover, these changes are found even at rest and in patients whose asthma is clinically controlled.

6. Conclusion

The CRediT authorship contribution statement

Carla L.F. Cavassini: Methodology, Investigation, Writing – review & editing. Evelin L.F.D. Gomes: Conceptualization, Methodology, Formal analysis, Supervision, Writing – review & editing. Josiane G. Luiz: Investigation, Writing – review & editing. Maisi C.M. David: Investigation, Writing – review & editing. Dirceu Costa: Conceptualization, Methodology, Writing – review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table 3
Optoeletronic data.

|                | Asthma | Control |
|----------------|--------|---------|
|                | Pre    | Post  Δ | p1 |
| Min volume (l/min) | 6.5 ± 3 | 9.9 ± 8.1| 3.4 | 0.131 |
| TV total(ml)     | 335 ± 226 | 401 ± 273 | 66 | 0.313 |
| Fr (hpm)        | 21 ± 6 | 23 ± 3 | 2 | 0.07 |
| Ti (sec)        | 1.28 ± 0.5 | 1.13 ± 0.2 | –0.15 | 0.188 |
| Te (sec)        | 1.73 ± 0.4 | 1.44 ± 0.2 | –0.29 | 0.04* |
| Ttot           | 3.01 ± 0.8 | 2.57 ± 0.3 | –0.44 | 0.06 |
| TV tx (ml)      | 148 ± 108 | 221 ± 258 | 73 | 0.305 |
| % TV tx        | 41.5 ± 10.8 | 38.8 ± 9.9 | 2.7 | 0.249 |
| TV in (ml)      | 0.05 ± 0.05 | 0.07 ± 0.03 | 0.02 | 0.123 |
| % TV in        | 17.6 ± 7.3 | 18.2 ± 8.6 | 0.6 | 0.784 |
| TV abd (ml)     | 128 ± 61 | 153 ± 123 | 25 | 0.372 |
| % TVabd        | 40.6 ± 11.8| 42.6 ± 12.9 | 2 | 0.502 |
| VRcp/Ti        | 0.11 ± 0.05 | 0.22 ± 0.32 | 0.11 | 0.183 |
| VAb/Ti         | 0.10 ± 0.03 | 0.14 ± 0.14 | 0.04 | 0.254 |
| VAb/Te         | 0.07 ± 0.03 | 0.11 ± 0.11 | 0.04 | 0.166 |

TV: tidal volume; Fr: respiratory frequency; Ti: inspiratory time in seconds; Te: expiratory time in seconds; Ttot: total cycle time; TV tx: thoracic Tidal Volume; TV abd: abdominal Tidal Volume; VRcp/Ti: abdomen total volume divided by inspiratory time; VAb/Ti: abdomen tidal volume divided by expiratory time; VAb/Te: abdomen tidal volume divided by the time (indices that assess the speed of muscle contraction calculated from the variables measured in the OEP) | p2|< 0.05 intergroup analysis; *p 1 < 0.05 intragroup analysis (ANOVA two-way pos hoc Bonferroni).

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