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Biophotogrammetry Model of Respiratory Motion Analysis Applied to Children

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Abstract - **This study aimed to test a protocol of measurements based on Biophotogrammetry to Analysis of Respiratory Mechanics (BARM) in healthy children. Seventeen normal spirometric children (six male and 11 female) were tested. Their performed maneuvers of forced inspiratory vital capacity were recorded in the supine position. The images were acquired by a digital camera, laterally placed to the trunk. Surface markers allowed that the files, exported to CorelDraw® software, were processed by irregular trapezoids paths. Compartments were defined in the thoracic (TX), abdominal (AB) and the chest wall (CW). They were defined at the end of an inspiration and expiration, both maximum, controlled by a digital spirometer. The result showed that the measured areas at the inspiratory and expiratory periods were statistically different (p<0.05). It reflects the mobility of CW and compartments. In conclusion, the proposed method can identify the breathing pattern of the measured subject using images in two dimensions (2D).**

Keywords—**respiratory mechanics, chest wall respiratory movements, photogrammetry, children.**

I. INTRODUCTION

THE act of breathing consists of inspiratory and expiratory actions. It provides an exchange of gases between the atmosphere and the body, essential action for the maintenance of human life [1].

At first moment, the inflow, the diaphragm contracts flattening on the abdomen while the external intercostal muscles separate from the ribs. There is the expansion of the rib cage as result of the air entering in the airways. This process generates an intrapulmonary pressure lower than external one. It generates around 20% anterior and posterior diameter increasing of the initial position [2].

Since the historical research of Konno and Mead [3], in the 1960´s, studies of the thoracoabdominal surface respiratory movements are considered effective to evaluate the performance of pulmonary function [4]. They were tested in different clinical conditions and at different ages [5], reflecting a direct relationship with the volume and respiratory pattern [6].

The use of equipments such as spirometers in respirometry and analysis of respiratory muscle strength are some of the methods of evaluation of this system. It has significantly contributed in assisting clinical diagnosis during the evaluation of physical performance in athletes [7]. However, the use of current technical standards for the collection of respiratory function measurements are, in many cases, impractical due to the need for expensive equipment [8].

Successfully used in previous studies [8],[9], biophotogrammetry proposes a low cost, simplified image acquisition and processing method. It´s focused on the kinematic two-dimensional evaluation (2D) of thoracoabdominal movement during specific respiratory maneuvers. The main advantages of biophotogrammetry have been its portability and the chance to following up patients under respiratory disorders treatment as much as following evolution of athletes.

Therefore, this study aimed to implement a measurement protocol based on the model of Biophotogrammetrics Analysis of Respiratory Mechanics (BARM) in normal spirometric children.

II. MATERIALS AND METHODS

An experimental, observational cross-sectional descriptive for the characteristics related to respiratory kinematic measurements of thoracoabdominal surface area study was conducted. Thus, an initial group of 22 children, 10 male and 12 female, had the terms of consent signed by their responsible. Exclusion criteria were applied to this initial group: (a) current or recent history of infectious processes, (b) history of allergic or respiratory diseases (c) cognitive impairment to follow the examiner's verbal commands during tests; (d) spirometric relationship between Forced Expiratory Volume in 1 second (FEV1) / Forced Vital Capacity (FVC) lower than 80%. Thus, at the end six males and 11 females were selected.

Information regarding age, weight, height, body mass index (BMI) and thoracic expansion (taken at residual volume and xiphoid process) were taken. In addition, the pulmonary function by spirometry was evaluated. The results only aimed at detecting normality.

The spirometry test followed the recommendations of the Brazilian Thoracic Society. It was held in a seated position using a Clement Clarke spirometer, model OneFlow.

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Maximum inspiratory and expiratory maneuvers lying at supine position were used as methodology for kinematics analysis of thoracoabdominal respiratory movements. It was filmed and a model of irregular quadrilaterals was drawn over the processed image. It is called Biophotogrammetry for the Analysis of Respiratory Mechanics (BARM). Each child was mapped in order to place the anatomical landmarks. These landmarks were highlighted through the use of 13 mm diameter spherical markers on the self-adhesive white surface, brand Pimaco®. Based on the procedures defined by palpatory anatomy, according [10], the markers were placed to indicate: (1) anterosuperior iliac spine; (2) omphalos scar plan; (3) inferior angle of the tenth rib; (4) sternum xiphoid appendix plan; (5) jugular notch plan (Fig. 1).

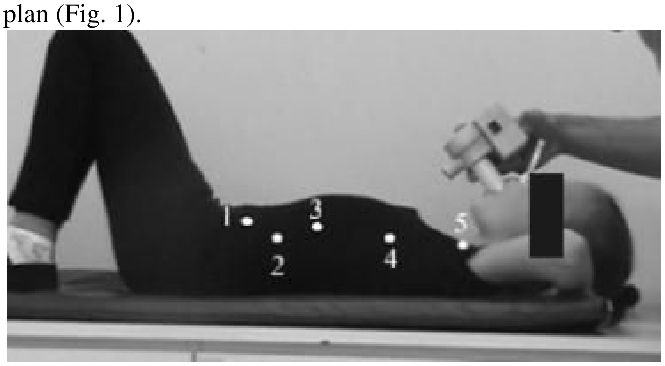

Fig. 1. Positioning for image acquisition of maximum respiratory maneuvers and anatomical landmarks used for drawing the BARM model: (1) iliac spine anterior superior, (2) omphalos scar plan, (3) inferior angle of the tenth rib, (4) xiphoid appendix plan, (5) jugular notch plan.

The children were then trained to perform forced inspiratory vital capacity (FIVC) maneuvers. A nose clip was used to prevent the air leakage during the picture acquisition of maximal respiratory maneuvers. A disposable mouthpiece attached to an electronic digital ventilometer AINCA (Model 00-295, with a range of measures from zero to 200 liters, and accurately referred to minimum flow of 5 ℓ/m - 100 ℓ/m (± 5%)) was used to control inspiratory volumes. Each child repeated the test three times perpendicularly positioned to the sagittal plan of the child on a 1.5 *m* high and 3 *m* away tripod. All maneuvers were recorded by a digital Sony camcorder model HDR-XR100. The best recorded measurement was considered.

The pictures of respiratory maneuvers were imported into the computing environment of the Windows Live MovieMaker® during image processing. Moments of inspiratory and expiratory apnea were extracted from its frames and then treated in CorelDraw® version 12 software.

The treatment of inspiratory and expiratory images was performed using BARM tracing model. The plans of the chest wall (CW) corresponding to the thoracic compartment (TX) and abdominal (AB) were then defined. The application of BARM model allowed calculation of the irregular quadrilaterals areas, or trapezoids, from linear measurements of their sides (Fig. 2). These measures were obtained by applying the CorelDraw® tool "linear dimension" Direct measurements obtained in the image were converted cm by using an element of known dimensions in the image, called calibrator. Areas in cm^2 were then calculated.

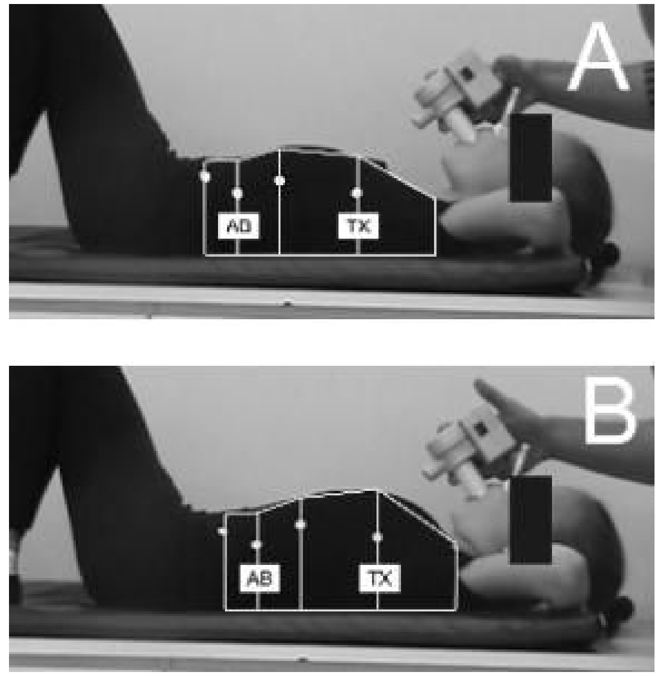

Fig. 2. Model BARM of irregular quadrilaterals, defined from the plans of the trunk with the surface markers, in condition of post-expiratory apnea (A) and performing forced inspiratory vital capacity maneuvers (B).

III. RESULTS

Five of the 22 children (who responded to the invitation to participate in this study with a consent form signed by parents) felt into one or more of the exclusion established criteria. Thus, 17 children composed the sample, 11 females and 6 males, whose characteristics are presented in Table 1.

TABLE I
CHARACTERISTICS OF THE STUDY GROUP AS A WHOLE, AND SEPARATED ACCORDING TO GENDER. VALUES PRESENTED IN MEDIAN (INTERQUARTILE RANGE).

Variable	General	Male	Female
N	17	6	11
Age (*years*)	9 (2)	10 (1.75)	9 (2)
Weight (*kg*)	32 (13.75)	42.3 (16.17)	27.6 (5.1)*
Height (*m*)	1.4 (0.11)	1.43(0.18)	1.36 (0.12)
BMI (kg/m^2)	16.10 (4.61)	19.75 (7.95)	15.23(2.39)*

*p<0.05

Large values were observed for all variables for the male group and the value of BMI puts the group as overweight classification (value between the percentile 85 and 95). Females had normal BMI general classification (percentile value between 5 and 85). Statistical differences were found for the variable weight and BMI.

The spirometric evaluation was applied as a ranking test for equalization of normal lung function for the study group. The best averages of spirometric indicators, considering the three conducted tests, were: (a) peak expiratory flow of 217.64 ± 52.47 ℓ/s, (b) FEV1 of 1.76 ± 0.69 ℓ, (c) VFC was 1.96 ± 0.59 ℓ, (c) FEV1/ VFC or Tiffenau Index of 0.9 ± 0.08%.

The area values obtained in the best execution of FIVC maneuver (ATX, AAB, ACW) (among the three performed by each children in both genders) are presented in Table 2. It´s also presented differences between inspiratory and expiratory areas (respiratory mobility) to the chest wall (MCW), thoracic compartments (MTX) and abdominal (MAB). The same table also lists the percentage rate of participation in each compartment (RTX, RAB) to full mobility of the chest wall and xiphoid circumference (CX). The found results between the genders were statistically different for the mobilization of inspired volumes (VolFIVC) and the magnitude of calculated inspiratory areas ($p < 0.05$).

TABLE II
OBTAINED RESULTS BY MEDIAN AND INTERQUARTILE RANGE (I.Q) OF THE BEST INDIVIDUAL MAXIMAL INSPIRATORY MANEUVER, CONSIDERING THE CLASSIFICATION OF CHILDREN ACCORDING TO GENDER.

	Male Median (I.Q.)	Female Median (I.Q.)
N	6	11
Vol_{FIVC} (ℓ)	1.75 (1)*	1.42 (0.34)*
C_X (*cm*)	79.3 (12.15)*	67 (5.5)*
A_{CW} (*cm²*)	489.64 (149.1)*	301.76 (43.59)*
A_{AB} (*cm²*)	162.42 (91.49)*	114.32 (37.64)*
A_{TX} (*cm²*)	301.17 (95.64)*	185.15 (40.7)*
M_{AB} (*cm²*)	24.78 (17.07)	15.25 (17.72)
M_{TX} (*cm²*)	25.1 (30.99)	32.56 (13.15)
M_{CW} (*cm²*)	45.77 (33.79)	42.25 (16.38)
R_{AB} (%)	51% (19%)*	34% (18%)*
R_{TX} (%)	49% (19%)*	66% (18%)*

Vol_{FIVC} = maximum inspiratory volume achieved in the best of three runs; Cx = xiphoid circumference; A_{CW} = inspiratory chest wall area, A_{TX} = area of the inspiratory thoracic compartment; A_{AB} = area of the inspiratory abdominal cavity, M_{AB} = abdominal mobility; M_{TX} = thoracic mobility, M_{CW} = mobility of the chest wall; R_{AB} = percentage contribution of the abdominal compartment to the mobility of the chest wall; R_{TX} = percentage contribution of the thoracic compartment for the mobility of the chest wall.

It was observed that inspiratory values were higher for males (1.75 ± 1 ℓ/min ♂, 1.42 ± 0.34 ℓ/min♀), such as increased total distensibility (489.64 ± 149.1 cm² ♂, 301.76 ± 43.59 cm² ♀), the female group had a higher percentage of chest use when compared with male group (66% vs. 49%). There were no statistical differences, when using the Mann-Whitney test for the variables Abdominal Difference, Thoracic Difference and Total Difference, $p = 0.098$, $p = 0.733$ and $p = 0.525$ respectively.

IV. Discussion

In the spirometric classification it was found that males had higher values for CVF than females. The same occurred to Vol_{FIVC}. The average values found for the FIVC maneuvers in males in this study were close to those found by Imhof *et al.* [11]. The median found in females is in line with prediction equations for lung volumes and capacities, which show values up to 25% lower in this gender [12]. Rassalan *et al.* [13] show that the increment in fat mass can affect the chest and diaphragm. This way, changing the lung function affects the gas transportation since there is an increment in respiratory effort which in turn. This was not a limiting factor in the male group yet. One possible explanation is that all children perform sport activities that contribute to better aerobic results.

Breathing is mandatory for life and the harmonization between the chest and abdomen systems provides the ideal conditions of adequate ventilation in individuals. Breathing can be classified in three possible categories: apical (standard chest), basal (abdominal pattern) and symmetrical or mixed (default thoracoabdominal) [14]. Each one recruit muscles in different proportions, varying the external format of the thoracoabdominal region [15] and may make the system more or less effective. Apolinário *et al.* [14] show that the respiratory cycle, without the proper use of abdominal (diaphragm) and thoracic region, causes an increment in energy consumption. It occurs due to failing to optimize the diffusion of oxygen.

Apical behavior uses the chest muscles (intercostals) and accessory (sternocleidomastoid and scalene) in higher proportions when reporting the breathing pattern. It affects the respiratory efficiency because they are muscles of high energy demand [1], [2]. This behavior, without depth, results in a reduced capacity of abdominal displacement avoiding an effective air renewal. This pattern is most commonly seen in strenuous exercises. It will lead the individual to a respiratory fatigue because (instead of an abdominal protrusion occurs and rib cage as in normal breathing) it uses the intercostal muscles and accessory action that sucks the diaphragm into the chest cavity. This movement limits the pulmonary compliance [16].

The values of R_{TX} and R_{AB} appear to be in line with the behavior recorded by researchers [9]. The average R_{AB} and R_{TX} was equivalent to 61% and 39%, respectively. This study found the average, with the distinction of gender, was 68% and 32% for females and 53% and 47% for males. A plausible explanation is found in studies which show the trend of running patterns for females and thoracic and thoracoabdominal breathing patterns for males. Besides, children from the seventh year of life tend to use abdominal breathing [17], [18].

The rate of growth in abdominal elastance contribution to the total elastance of the respiratory system is also explained by the progressive mineralization of the ribs as children grow. There is an increment in the ratio bone/costal cartilage composition, hardening the chest, which also increases the thoracic elastance during childhood [19]. In other words, the two compartments increase their elastance, become more rigid and more tonic to distensibility in relation to the total elastance of the respiratory system but in different at times and proportions. In children, the initial growth in abdominal elastance, leads to greater use of thoracic mobility, whose ribs still requires mineralization. In the adult, with the thoracic framework completely mineralized, abdominal mobility, lying in the supine posture, is the most biomechanically efficient feature for mobilization of high-volumes of air.

Research in the last 15 years with the incorporation of new technologies, especially those based on images [4], [6], [20] has enhanced the discussions about how the kinematic analysis of thoracoabdominal breathing movements can be associated with different variables.

V. Conclusion

The proposed method can identify the breathing pattern of the sample measured using images in two dimensions (2D).

The advantages of two-dimensional analysis are the possibility for locally testing due to ease of resources transportation, low cost of involved material and the lack of devices that constrict or changing functional pattern of the required maneuvers. The quantification of respiration based on the variation in lung volume through the displacement of the thoracoabdominal structures may also be a strategy to promote the early quantitative identification of imbalances in the respiratory system.

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