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Functional exercise capacity, lung function and chest wall deformity in patients with adolescent idiopathic scoliosis

Capacidade funcional de exercício, função pulmonar e geometria da caixa torácica em pacientes com escoliose idiopática do adolescente

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Abstract

Introduction: The adolescent idiopathic scoliosis (AIS) causes changes on the compliance of the chest. These changes may be associated with impaired lung function and reduced functional exercise capacity of these adolescents. We aimed to evaluate the correlation between functional exercise capacity, lung function and geometry of the chest at different stages of AIS. **Materials and methods**: The study was carried out in a cross-sectional design which were evaluated 27 AIS patients at different stages of the disease. For chest wall evaluation, were created geometry angles/distances (A/D), which were quantified by Software Postural Assessment. The functional exercise capacity was assessed by a portable gas analyzer during the incremental shuttle walk test (ISWT). Besides that, manovacuometry and spirometry were also performed. **Results**: Linear regressions

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showed that oxygen uptake (peak VO2) was correlated with distance travelled in the ISWT (R2 = 0.52), maximal respiratory pressures, cough peak flow (R2 = 0.59) and some thoracic deformity markers (D1, D2 and A6). **Discussion**: We observed that the chest wall alterations, lung function and respiratory muscle strength are related to the functional exercise capacity and may impair the physical activity performance in AIS patients. **Final considerations**: There is correlation between functional exercise capacity, lung function and geometry of the chest in AIS patients. Our results point to the possible impact of the AIS in the physical activities of these adolescents. Therefore, efforts to prevent the disease progression are extremely important.

Keywords: Chest. Pulmonary function testing respiratory mechanics. Scoliosis.

Resumo

Introdução*: A escoliose idiopática do adolescente (EIA) provoca alterações na conformidade da caixa torácica. Essas alterações podem estar associadas ao prejuízo da função pulmonar e à redução da capacidade funcional de exercício desses adolescentes.* ***Materiais e métodos****: O estudo foi realizado em delineamento transversal no qual foram avaliadas a correlação entre a capacidade funcional de exercício, função pulmonar e a geometria da caixa torácica de 27 pacientes em diferentes estágios da EIA. Para avaliação da geometria torácica foram criados ângulos/distâncias (A/D) que foram quantificados pelo Software de Avaliação Postural. Foram realizadas manovacuometria, espirometria e a capacidade funcional de exercício foi avaliada por meio de um analisador de gases portátil durante o incremental shuttle walk test (ISWT).* ***Resultados****: As regressões lineares mostraram que o consumo de oxigênio se correlacionou com a distância caminhada no ISWT (R2 = 0,52), as pressões respiratórias máximas, o pico de fluxo de tosse (R2 = 0,59) e alguns marcadores de deformidade torácica (D1, D2 e A6).* ***Discussão****: Observamos que a alteração da geometria da caixa torácica, a função pulmonar e a força dos músculos respiratórios estão associadas à capacidade funcional de exercício e podem prejudicar o desempenho das atividades físicas dos pacientes com EIA.* ***Considerações finais****: Existe correlação entre a capacidade funcional de exercício, função pulmonar e a geometria da caixa torácica em pacientes com EIA. Nossos resultados apontam o possível impacto da EIA nas atividades físicas desses adolescentes.*

Palavras-chave*: Caixa torácica. Teste de função pulmonar. Mecânica respiratória. Escoliose.*

Introduction

The adolescent idiopathic scoliosis (AIS) is the most common type of scoliosis. Its prevalence is estimated at between 2% and 4% of all adolescents aged 10 to 16 years old (1), affecting mainly females at a ratio of 3.5:1 (2).

Because of the complex interconnections between sternum, ribs and spine, the displacement and rotation of the vertebrae have a profound effect on the shape of the chest, creating a convex and a concave side (3). The rib cage provides the structure that contains the lungs and supports the respiratory muscles. The normal ventilatory mechanics depends on a compliant rib cage and the distortion of the rib cage associated with spinal deformity contributes to altered ventilatory mechanics (4, 5) and decreased ability to perform physical activities in EIA subjects (6). Additionally, chronic muscular weakness may play a role in the lack of muscular and cardiorespiratory fitness (6, 7).

A direct relationship between the decreased maximal aerobic capacity and forced vital capacity has also been reported in AIS patients (8). It is also seen that aerobic exercise improves the forced vital capacity and inspiratory capacity of these patients and positively influences the cardiorespiratory fitness (7).

Believing that AIS patients have reduced functional exercise capacity associated with the impaired lung function and chest geometry, the aim of this study was to evaluate the correlation between these variables in patients at different stages of the disease.

Methods

The study was conducted in a cross-section design. We enrolled patients with AIS of both gender aging between 11 and 18 years. Patients with previous or current history of heart, lung, or neuromuscular disease and patients who, for any reason, failed to perform the assessments proposed were excluded. Patients were asked about their level of physical activity in their daily life, and those who reported to be physically active (9) were also excluded. Patients were referred to the Orthopedic Clinic of a local hospital, where they underwent radiographic evaluation of Cobb angles. All the study participants signed informed consents. The present study was approved by the local ethics committee (No. 86955).

Initially were evaluated 29 patients, one was excluded due to asthma and one for failing to perform the evaluations. Eight of these patients were preoperatively and nineteen underwent surgical treatment of spinal arthrodesis. All patients were classified as Lenke I, with deviation of the main thoracic curve to the right. The respiratory muscle strength, lung function, exercise capacity and chest wall shape were evaluated.

Anthropometrics

Weight and height were measured by standard techniques. Weight was assessed to the nearest 0.1 kg, and height was measured to the nearest 0.5 cm. The body mass index was calculated by dividing weight in kilograms by height in square meters (kg/m^2).

Respiratory assessment

The respiratory muscle strength was quantified by measuring the maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) according to the Brazilian Thoracic Association statement (10). These measurements were performed with the participant properly seated and using a manometer (MVD 300 model; Globalmed, São Paulo, SP, Brazil). The MIP and MEP were performed from functional residual capacity.

Spirometry was performed using a handheld spirometer (Spiropalm; COSMED, Pavona di Albano, Italy) according to the Brazilian Thoracic Association recommendations (10). Forced vital capacity (FVC), forced expiratory volume in the first second of expiration (FEV_1), and the FEV_1/FVC ratio were quantified and were expressed as absolute values and as percentage of predicted values (11). Peak cough flow (PCF) was carried out using the method described by Fiore et al. (12).

Incremental shuttle walk test

The ISWT was performed according to the methods described by Singh et al. (13). The walking velocity was imposed by audio signals recorded on a CD. Heart rate (HR), blood pressure, and dyspnea and leg fatigue (Borg scale) were determined before and after each ISWT. The test was performed twice to minimize the learning effect. The interval between tests was set at 30 minutes and/or the return of the aforementioned variables at baseline. The distance walked during the second test was considered for further analysis.

During the second ISWT, the expired gases were collected and analyzed with a portable telemetric gas analyzer (K4b2; Cosmed, Pavona di Albano, Italy). The calibrations with room air, reference gas, 3 L syringe, and delay were performed following the manufacturer's recommendations.

Oxygen uptake, VCO_2, VE, tidal volume (VT), respiratory rate (f), ventilatory equivalents of O_2 (VE/VO_2) and CO_2 (VE/VCO_2), the rate of gas exchange (R), HR, and pulse of O_2 (PuO_2) as well as other variables obtained by calculations were assessed breath by breath. After collecting these variables, the data were filtered every 15 seconds for further analysis.

Chest wall evaluation

The CWS deformities were evaluated using SAPO. This program is available for free on the internet (http://puig.pro.br/sapo/). Individuals standed in a location previously marked at 3.0 m from the camera. A digital camera (SONY Cyber-Shot DCS-W300) was positioned parallel to the floor, with the aid of a professional tripod positioned at half the height of the individual. We positioned a plumb line, with a tag of one meter, from the ceiling of the room for calibration of the photos in an upright position. The pictures were taken in the anterior view, left side, right side and posterior view. An Ethylene Vinyl Acetate (EVA) carpet was used in order to mark the feet position for each photo taken. The anatomical points were marked on the skin by fixing half sphere of styrofoam balls of 25 mm diameter, using double-sided tape. These markings are shown in Figure 1. The anatomical points used were based on the SAPO protocol, except point 1 (14) and points 3, 4 and 5 that were created by our research team. We evaluated the thoracic markers by angles (A) and distances (D) as follows (Figures 2 and 3, respectively): A1 (right acromion/manubrium/left acromion); A2 (right acromion/xiphoid/left acromion); A3 (last false right rib/xiphoid/last false left rib); A4 (angle between the deepest point of the waist and upper and lower edges of the waist); A5 (inframamilar/inferior angle of the scapula/right and left acromion); A6 (C7/acromion right and left/T3); A7 (angle formed by the intersection of the tangent segments of the upper and lower scapulae angles); D1 (xiphoid–last false rib on the right and left side); D2 (manubrium–last false rib on the right and left side); and D3 (xiphoid–anterior superior iliac spine on the left and right side). All these angles and distances were created by our team, except the A1 angle, which was reproduced from the study of Davidson et al. (14).

Statistical analysis

The data were analyzed descriptively and presented as mean and standard deviation when presented symmetrical distribution and as median (variance) when presented asymmetric distribution. The normality of the variables was investigated by Kolmogorov-Smirnov test. A series of linear regressions were performed to assess the correlations between variables. The probability of an alpha error was set at 5%.

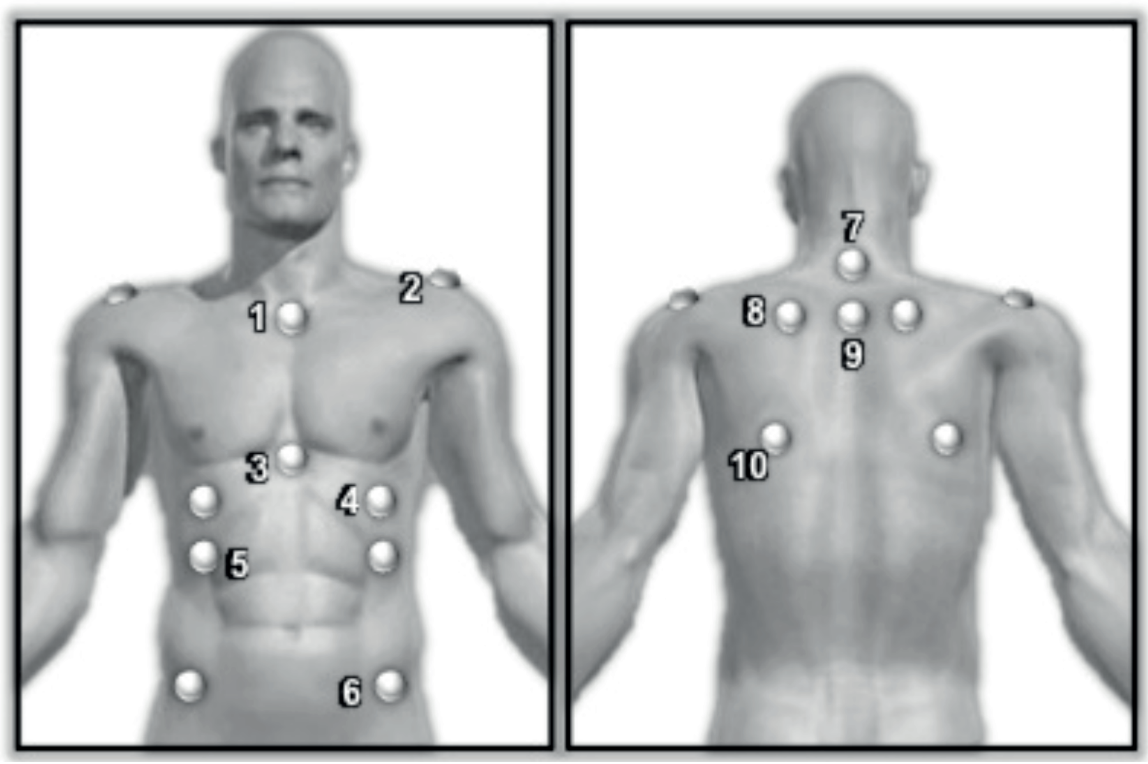

Figure 1 – Anatomical points

Note: 1 = manubrium; 2 = acromion; 3 = xiphoid process; 4 = inframamilar region (half the distance between nipple and last false rib); 5 = last false rib (intersection of the nipple line with the last false rib line); 6 = anterior superior iliac spine (ASIS); 7 = spinous process of C7; 8 = superior angle of the scapula; 9 = spinous process of T3; 10 = inferior angle of the scapula.

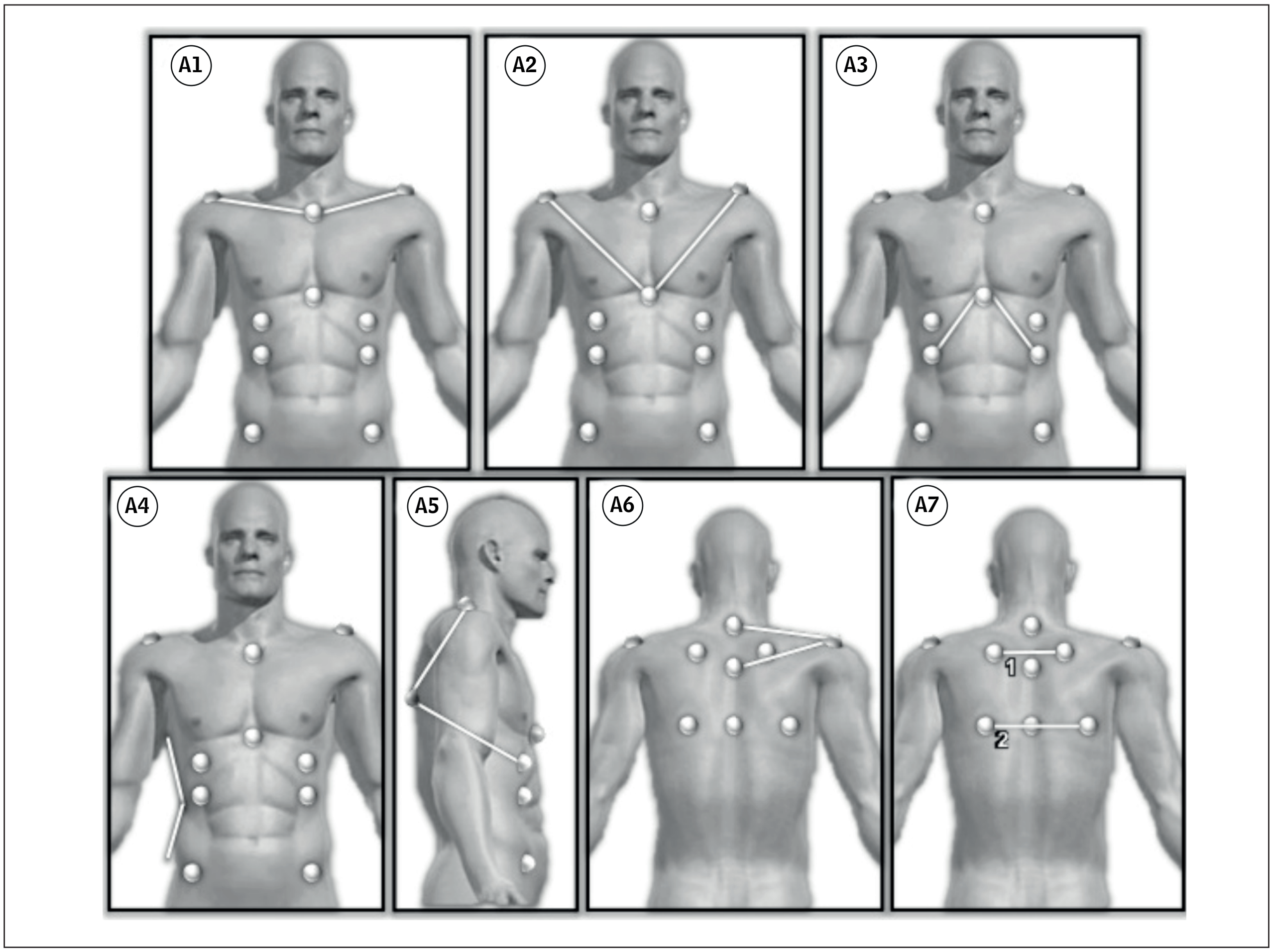

Figure 2 – Angles

Note: A1 = right acromion/manubrium/left acromion; A2 = right acromion/xiphoid/left acromion; A3 = last false right rib/xiphoid/last false left rib; A4 = angle between the deepest point of the waist and upper and lower edges of the waist; A5 = inframamilar/inferior angle of the scapula/right and left acromion; A6 = C7/acromion right and left/T3; A7 = angle formed by the intersection of the tangent segments of the upper and lower scapulae angles.

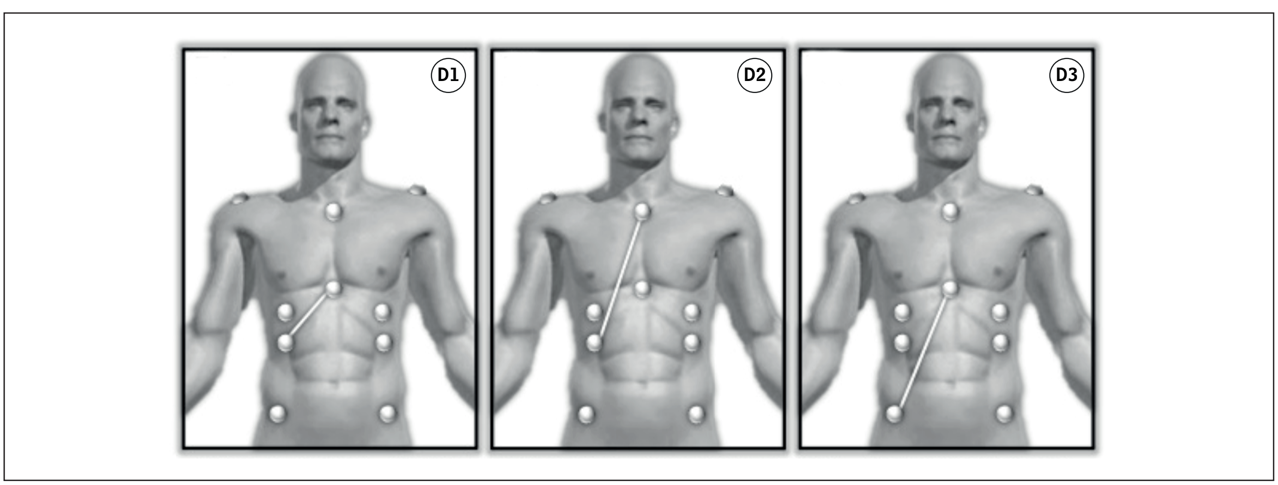

Figure 3 – Distances

Note: D1 = xiphoid–last false rib on the right and left side; D2 = manubrium–last false rib on the right and left side; D3 = xiphoid–anterior superior iliac spine on the left and right side.

Results

The characteristics of the 27 patients, 24 females, are shown in Table 1. The average BMI shows that individuals had low weight (18.5 ± 2.6). By the average of predicted FVC and FEV_1/FVC ratio, we could identify a restrictive component in these patients (76.9 ± 11.9 and 0.9 ± 0.1, respectively). Linear regression showed that the highest correlation was obtained between peak VO_2 and ISWD (R^2 = 0.52; p < 0.001). In addition to this, we found correlation between peak VO_2 and MIP (R^2 = 0.17; p = 0.029), MEP (R^2 = 0.24; p = 0.008), PCF (R^2 = 0.59; p < 0.001), D1 (R^2 = 0.19; p = 0.023), D2 (R^2 = 0.29; p = 0.003), and A6 (R^2 = 0.16; p = 0.037) as shown in Figure 4. We have also obtained correlation between VE_{max} and MIP (R^2 = 0.19; p = 0.023), MEP (R^2 = 0.21; p = 0.015), PCF (R^2 = 0.57; p < 0.001), D1 (R^2 = 0.22; p = 0.013) and D2 (R^2 = 0.34; p = 0.001). The last dependent variable, ISWD, showed correlation with MIP (R^2 = 0.20; p = 0.019) and MEP (R^2 = 0.19; p = 0.021), FEV_1 (R^2 = 0.38; p < 0.001) and A5 (R^2 = 0.18; p = 0.027).

Table 1 - Demographic, anthropometric, lung function and respiratory muscle strength of the 27 patients

Variables	Mean (± SD)
Age (years)	15.7 (± 3.3)
Height (m)	1.65 (± 0.09)
Weight (kg)	50.6 (± 9.7)
BMI (kg/m^2)	18.5 (± 2.6)
FVC predicted (%)	76.9 (± 11.9)
FEV1 predicted (%)	78.6 (± 15.4)
FEV1/FVC	0.9 (± 0.1)
PCF (L)	6.1 (± 1.4)
MIP (cmH_2O)	70 (± 25)
MEP (cmH_2O)	69 (± 30)
1^{st} ISWD (m)	432.8 (± 98.9)
2^{nd} ISWD (m)	453.08 (± 103.30)

Note: Note: BMI = body mass index; FVC = forced vital capacity; FEV1 = forced expiratory volume in 1st second; PCF = peak cough flow; MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure; ISWD = incremental shuttle walk distance.

Discussion

This study evaluated cardiorespiratory fitness and the chest wall shape of adolescents with EIA. Positive correlations between metabolic variables and thoracic deformity markers, lung function and respiratory muscle strength were established. We observed that the deformation of the rib cage can change the physical performance of these patients.

In our study there was a correlation between peak VO_2 and chest wall shape, which shows how the deformity can possibly alter the ventilatory efficiency and compromise the physical ability in AIS patients. The thoracic deformity markers that correlated with peak VO_2 were the A6, D1 and D2, representing the rotation of the chest wall. Other studies have also found a relationship of magnitude of scoliosis with the physical capacity. Czaprowski et al. (6) submitted moderate AIS (Cobb angle between 25° and 40°) patients to submaximal exercise test and found negative correlation between peak VO_2 and Cobb angle. Another finding in our study was the correlation between peak VO_2 and maximal respiratory pressures, the PCF and the ISWD. This shows the influence of respiratory muscle function on the physical performance of AIS patients.

Martínez-Llorens et al. (15) also found positive correlation between exercise capacity, represented by the maximum work rate, and respiratory pressures. In addition, a positive correlation was established between respiratory muscle strength and FVC. The reduction in respiratory muscle strength and pulmonary restriction are well-described characteristics in AIS patients (8, 15-17).

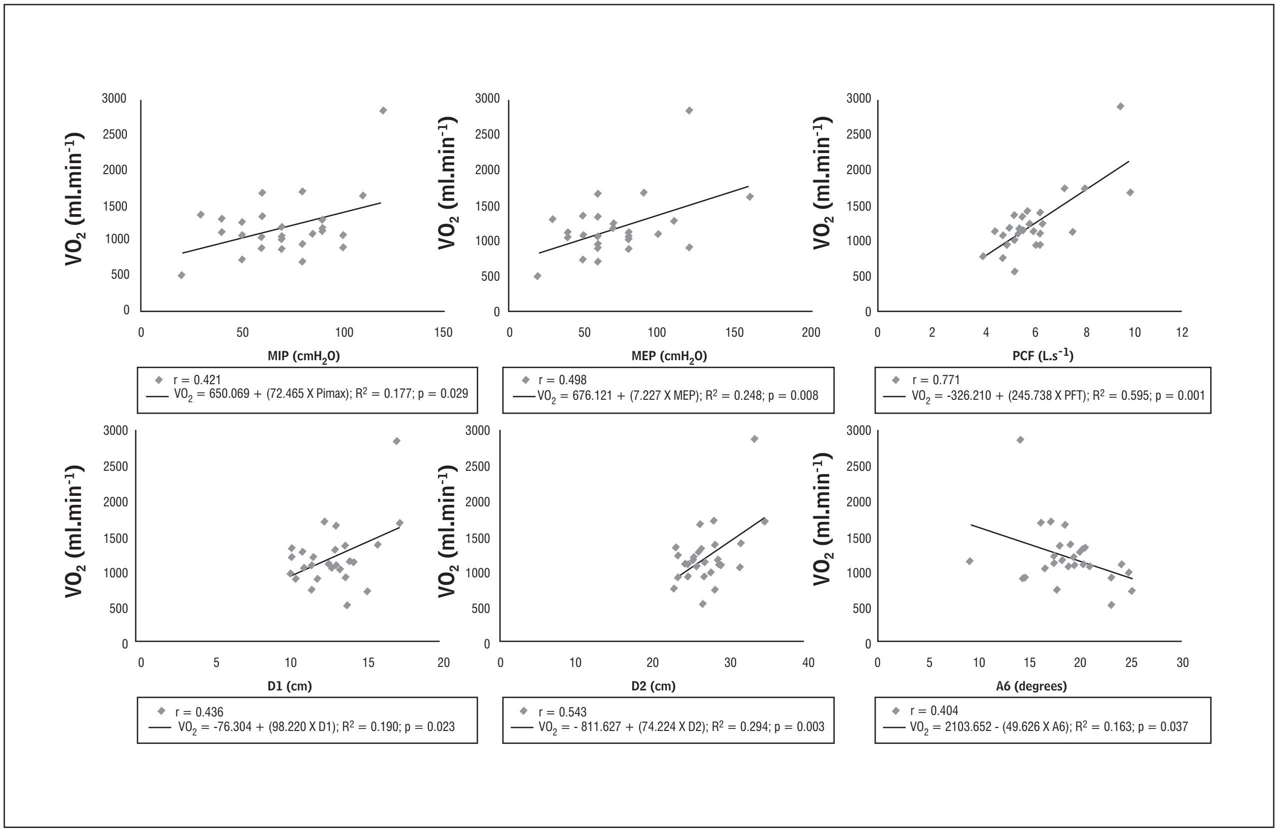

Figure 4 – Significant correlations among oxygen uptake (VO_2), maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), peak cough flow (PCF), distance 1 (D1), distance 2 (D2) and angle 6 (A6)

In addition, VE_{max} was also imparied. In this study there was a positive correlation between VE_{max} and thoracic deformity markers D1 and D2, which confirms the influence of thoracic deformity ventilation in AIS patients. This finding is consistent with the results of Barrios et al. (18) which found lower VE_{max} values relative to peers controls and this variable was correlated negatively with the magnitude of scoliosis curvature, measured by Cobb angle. Another result that suggests the ventilatory inefficiency of these patients is the increased respiratory oxygen equivalent (VE/VO_2). During the exercise, the respiratory rate is significantly higher in AIS patients than in healthy people (15, 18). This increased respiratory rate can be explained as a compensatory mechanism adopted in response to the low tidal volume and the fact that they do not present good efficiency on the variation of the respiratory pattern. Thus, in case of increased oxygen demand to the body, there is an increase in respiratory rate to compensate the limitation of diaphragmatic incursion (19, 20).

These studies showed that, even with the increased respiratory frequency, VE_{max} is reduced in patients with AIS, which shows the inefficiency of mechanical ventilation of patients. We may suggest through our results that the reduction in respiratory muscle strength may lead to reduction of VE_{max}, once we found correlation between VE_{max} and respiratory pressures. Likewise, the VE_{max} correlated with PCF, showing that the smaller the VE_{max}, the lower the PCF. Following the same assumption, the PCF can be reduced following the reduction in respiratory pressures. Previously, we observed that AIS patients have a respiratory pattern consistent with pulmonary restriction. Our patients had significantly shallower slope of ΔVT/ΔlnVE, that is, worse breathing pattern during walking. Associated with lower VE and VT at the end of the ISWT, these results clearly show the restrictive ventilatory pattern in response to exercise (8). This inefficiency, coupled with the low ventilatory capacity and low VO_{2max} may be responsible for reduced exercise tolerance in patients with AIS.

Another positive correlation found in our study was between the dependent variable ISWD and maximal respiratory pressures, FEV_1, and the A5 thoracic deformity marker. The relationship between these variables seems quite intuitive, as the higher the strength of respiratory muscles and better lung function, the greater will be the ISWD. The same goes to thoracic marker A5, since it represents the thoracic spinal deformity of the patient. The higher the value of this angle, the lower the deformity of the patient and, probably, the mechanical ventilation should be less impaired. In a recent study that also evaluated the distance covered in walk test in AIS patients showed that the distance covered during the test was significantly lower in AIS patients when compared to healthy individuals. In the distance, this study showed that during the walk test, AIS patients had higher heart rate, Borg scores and lower values of oxygen saturation (21). These findings show that, for reasons still not fully understood, AIS patients have lower exercise tolerance. Patients evaluated in our study had lung function values below the expected normal values. The average predicted FVC was 77%, indicating that most of the patients had restrictive lung disease. DiRocco and Vaccaro (22) also found reduced FVC in AIS patients under 17, with an average Cobb angle of 21 degrees. Nevertheless, the study of Barrios et al. (18) does not corroborate with these findings. The cause of mechanical inefficiency during breathing in AIS patients is due to distortion of the spine and chest wall, accompanied by bone structure stiffness, leading to lower thoracic mobility (23, 24). However, ventilatory failure appears not to be the only responsible for the low exercise capacity of AIS patients. Martínez-Llorens et al. (15) evaluated the strength of peripheral muscles besides respiratory muscles, and it was observed that these patients have generalized muscle dysfunction. In addition, the authors state that the weakness of the AIS is not only widespread as is the main cause of exercise intolerance in these patients, since it is present even in the absence of ventilatory impairment. One hypothesis of the cause of muscle tone dysfunction is genetic predisposition, which would develop a flexible spine and, therefore, not resist the growth spurt without modification (25).

The implementation of walking-based aerobic exercises would be rational strategy for the treatment of patients with AIS. dos Santos Alves et al. (7) found a significant improvement in FVC, inspiratory capacity, FEV_1, and increased 6MWD after aerobic exercises in patients with AIS. Another similar study observed 48% improvement in aerobic capacity in the trained group and 9.2% decrease in the control group (26). In addiction, the manual therapy aided with Dynamic Brace System has improved the respiratory parameters and trunk morphology value (27). These studies show that, in fact, regular aerobic exercises and strength training (28, 29) play an important role in the treatment of patients with AIS.

This study has limitations that should be described. We did not inform the Cobb angles of the patients; this is justified by the fact that most patients in the postoperative period did not return to the column clinic for a routine visit and the radiographic imaging for evaluation of the angle. To increase the sample size was necessary to cluster patients in different stages of the disease, both preoperatively and postoperatively. Besides, we did not perform the CPET for comparison of variables obtained during ISWT. However, our main objective was to quantify the reduction in functional exercise capacity (ie, ability to walk), and furthermore, the ISWT has been widely correlated with CPET and is suitable for evaluating aerobic capacity in healthy middle-aged and older adults in patients with chronic diseases. In addition, studies that evaluated the functional exercise capacity of AIS patients used the 6MWT. Although the 6MWT is considered intense (30), the ISWT provoked a significantly higher VO_2, VCO_2, VE_{max} and FC_{max} compared to 6MWT (31).

We can conclude that there is a correlation between peak VO_2 variables, VE_{max} and ISWD with maximal respiratory pressures, lung function and chest wall shape AIS patients. These correlations show the influence of the alterations of the chest wall shape in functional exercise capacity and how the disease is likely to limit the activities of daily living of these adolescents. However, studies comparing pre and postoperative are needed in order to better clarify the influence of the chest wall deformity on the functional exercise capacity.

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