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Clinical Study

Severe hyperkyphosis reduces the aerobic capacity and maximal exercise tolerance in patients with Scheuermann disease

Alejandro Lorente, MD, PhD[a], Carlos Barrios, MD, PhD[b,*], Rafael Lorente, MD, PhD[c], Rocío Tamariz, MD[d], Jesús Burgos, MD, PhD[a]

[a] *Department of Orthopedic Surgery, Hospital Ramón y Cajal, Ctra. de Colmenar Viejo, km. 9.100, Madrid 28034, Spain*
[b] *Institute for Research on Musculoskeletal Disorders, School of Medicine, Valencia Catholic University, Quevedo 2, Valencia 46001, Spain*
[c] *Department of Orthopedic Surgery and Traumatology, Hospital Infanta Cristina, Av. Elvas, s/n, 06006 Badajoz, Spain*
[d] *Department of Pediatric Cardiology, Hospital Ramón y Cajal, Ctra. de Colmenar Viejo, km. 9.100, Madrid 28034, Spain*

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Abstract

BACKGROUND CONTEXT: The evaluation of ventilatory functional restrictions during a maximal exercise tolerance test in patients with Scheuermann disease has never been described.
PURPOSE: This study evaluated the respiratory functional capacity of patients with Scheuermann disease compared to healthy adolescents matched in age.
STUDY DESIGN/SETTING: Prospective comparative study.
PATIENTS SAMPLE: Forty-one consecutive adolescents with Scheuermann hyperkyphosis (SK) and 20 healthy controls matched in age were included in the study.
OUTCOME MEASURES: Basal spirometry and dynamic ventilatory parameters were measured during a maximal cardiopulmonary exercise tolerance test. Heart rate, oxygen saturation ($SatO_2$), maximum oxygen uptake (VO_2 max), quotient between ventilation and volume of exhaled carbon dioxide (VE/CO_2), respiratory exchange rate (RER), ventilatory capacity at maximal exercise (VEmax), and test duration were recorded at initium and at maximal exercise.
METHODS: The exercise tolerance test (ETT) was completed to exhaustion using a standard Bruce protocol on a ramp treadmill. Comparisons of quantitative variables between SK and control group were analyzed by statistical nonparametric test. The correlations between the magnitude of the thoracic kyphosis and both the VO_2 max/kg and VEmax of the SK group were also analyzed. No funds were required. The authors have no conflicts of interests.
RESULTS: Patients with SK started the test with a higher heart rate ($p<.01$) and reached exhaustion with a lower heart rate ($p<.05$) than healthy controls. At maximal exercise, the $SatO_2$ was declined in Scheuermann patients compared to healthy subjects ($p<.05$). The maximal aerobic power (VO_2max) was greater in healthy controls than in hyperkyphotic patients (50.0 ± 6.7 vs. 43.4 ± 11.3 mL/kg/min; $p<.05$). There was an inverse correlation between the increase in the magnitude of thoracic kyphosis and the deterioration of the maximal aerobic power. VO_2max and VEmax were severely deteriorated in patients with more than 75° kyphosis. Patients with >75° thoracic kyphosis also showed an impairment in their cardiovascular efficiency as measured by the heart rate/VO_2 quotient. The limited tolerance to the exercise in SK patients was reflected by a shorter duration of the exercise test and a lower energy cost measured in METS (metabolic equivalents) as compared to healthy controls.
CONCLUSIONS: Patients with severe hyperkyphosis (>75°) show significant respiratory inefficiency together with a lower ventilation capacity and lower VO_2max. There is an inverse

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* Corresponding author. Institute for Research on Musculoskeletal Disorders, School of Medicine, Valencia Catholic University, Quevedo 2, Valencia 46001, Spain. Tel.: (+34)610408001; fax: (+34) 963944590.
E-mail address: carlos.barrios@ucv.es (C. Barrios).

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correlation between the increase in the magnitude of thoracic kyphosis and the deterioration of the maximal aerobic power.

Keywords: Cardiopulmonary exercise test; Hyperkyphosis; Maximal oxygen uptake; Respiratory function; Scheuermann disease; Ventilatory efficiency.

Introduction

Scheuermann disease (SD) is a spinal disorder named after Dr Holger Werfel Scheuermann, who, in 1921, first described a structural thoracic kyphosis mainly affecting adolescents [1]. The best-known manifestations are multiple wedged vertebrae and thoracic kyphosis known as Scheuermann kyphosis (SK). The classic diagnostic criteria include "three or more consecutive wedged thoracic vertebrae," as proposed by Sorensen in 1964 [2]. However, SD pathological changes also include disc and endplate lesions, primarily Schmorl's nodes and irregular vertebral endplates [1,2].

In contrast to the extensive investigation concerning the influence of idiopathic scoliosis on the respiratory function [3,4], few reports have addressed the impact of SK on pulmonary physiology. Murray et al. [5] reported decreased vital capacity and restrictive lung disease in cases with kyphosis greater than 100°. Diminished pulmonary function was classically defined by Weng and Levison [6] as less than 80% of the expected forced vital capacity (FVC) and/or forced expiratory volume in 1 second (FEV1). Abbi et al. [7] found that the percentage of the predicted FVC decreased significantly with increasing degrees of kyphosis from 105% in cases with kyphosis ranging 71° to 80°, to 83% in those from 81° to 90°, and 73% in cases with kyphosis greater than 90°. These authors also showed that the greatest kyphosis revealed a fairly weak but significant correlation with the percentage of predicted FVC.

All previous studies addressing pulmonary function in SK patients used static or baseline spirometry determinations. The small restrictions found at rest do not seem to limit the functional ventilatory capacity for daily activities [5,7]. As in adolescents with idiopathic scoliosis, the slight baseline ventilatory restrictions found by conventional spirometry can be amplified by a cardiopulmonary maximal exercise tolerance test (CPET), as the demands of pulmonary function are severely increased during intensive physical work [8]. In addition to this advantage, the evaluation of cardiorespiratory functional restrictions during a maximal CPET has never been described in patients with SK.

To our knowledge, there is a lack of information about tolerance to maximal exercise in patients with hyperkyphosis related to SK. We therefore conducted a study to evaluate the cardiorespiratory functional capacity of patients with SK compared to that of healthy adolescents matched in age. The hypothesis was that severe hyperkyphosis could reduce the aerobic capacity and maximal exercise tolerance in these patients.

Materials and methods

Patient inclusion criteria

We performed a prospective study including a series of consecutive patients with Scheuermann disease from our daily spine outpatient clinic who had more than 60° Cobb degrees and were aged between 12 and 17 years. The objective of the research was explained to all subjects, and the proper informed consent was obtained. None of the patients refused to participate. The study protocol was approved by the clinical research ethics committees at the main institution (Ref. #v1:08/05/2016).

Patients were eligible for inclusion if they had a diagnosis of Scheuermann disease and had not yet received surgical intervention. In all patients, the function of the lower extremities was neurologically examined to exclude signs of a possible myelopathy, specifically in high degree kyphosis patients. Other exclusion criteria were the presence of congenital heart disease or other pulmonary diseases, such as asthma or bronchiectasis. Volunteers who were healthy boys and girls matched in age participated in the study as a control group. Healthy controls were recruited from the group of patients referred to our orthopedics outpatient clinic by pediatricians or general practitioners for suspicion of orthopedic pathology other than spine disorders or complaints (usually lower extremity or foot complaints). All these volunteers were first screened for the exclusion of vertebral pathology through a clinical exam and X-ray studies of the whole spine in coronal and sagittal views.

Both groups were also clinically assessed to exclude cases with acute or chronic respiratory conditions such as asthma that could introduce distortions in the results. A basal 12-lead electrocardiogram was registered in all cases to determine the presence of unknown cardiac dysfunction according to standardized guidelines [9].

Healthy controls were only active within regular school-prescribed twice per week activities. Healthy volunteers exceeding these limits for any reason were excluded from the study since regular athletic training induces better aerobic parameters that could introduce bias into the study. Scheuermann patients were also determined to have the same habits of practicing sports as the healthy population (they were involved in school sports activities and in leisure sports). Both the healthy controls and the Scheuermann patients were European Caucasian individuals.

At the time of collecting the sample of patients with SK, 62 patients were initially assessed. A total of 21 cases were

excluded for different reasons. Four patients exhibit associated scoliotic deformity; 3 patients had congenital cardiopathy; in 3 patients, the hyperkyphosis was part of a musculoskeletal syndromic pathology; 11 patients showed large thoracolumbar hypokyphotic curves with apex at T11 or below. These last patients were excluded because the thoracic spine below T10 has almost no participation in the respiratory movements [10,11].

Radiographic assessment

Two spine surgeons independently measured the magnitude of the total T2–T12 thoracic kyphosis on a full-length lateral radiograph according to the Cobb method [12] and reached a consensus. The radiograph was made with the patient in a standing position. The radiographic assessments were made <4 weeks before the ETT.

Cardiopulmonary exercise test

CPETs were conducted using a Schiller Cardiovit CS-200 Ergo-Spiro Stress Test System (Baar, Switzerland), which allowed measurement of both spirometric static parameters and cardiorespiratory functional parameters. Baseline pulmonary function was measured on the same day, immediately before administration of the CPET. FEV1 was recorded as a spirometric static parameter.

CPETs were conducted under similar conditions than those of previous studies [3] following a standard Bruce protocol [13] for each of the patients and with the use of a motorized treadmill adapted to the ergometer to take measurements during the test. Standard conditions of temperature, humidity, and atmospheric pressure were maintained according to normalized guidelines [9]. Continuous 8-lead electrocardiogram monitoring was used during exercise. The study protocol began with a 5-minute warm-up period at a speed of 0.75 m/s (2.7 km/hr). Subsequently, the speed was increased by increments of 0.2 m/s (0.72 km/hr) per minute. The slope of the treadmill was constantly maintained at 1.5%, resembling the normal resistance of air.

Three types of variables reflecting cardiovascular function, ventilatory capacity, and metabolic gas exchange were all measured during the CPET. Cardiovascular function was assessed by recording the heart rate (HR), blood pressure (BP), and oxygen saturation ($SatO_2$) at the beginning and the end of the test. Metabolic gas exchange and ventilatory parameters were measured ''breath by breath'' using a respiratory valve and face mask (Hans Rudolph, Inc., Kansas City, MO, USA), through a Schiller gas analyzer (Baar, Switzerland). The test duration was also recorded.

Finally, the metabolic equivalents of tasks (METS) were considered to quantify the energy cost that require the participants to reach their maximal functional capacity. A MET is defined as the resting metabolic rate, that is, the amount of oxygen consumed at rest, estimated approximately in 3.5 mL O_2/kg/min (1.2 kcal/min for a 70-kg person) [14]. As such, work at 5 METS requires five times the resting metabolism, that is 17.5 mL O_2/kg/min and 10 METS requires ten times the resting metabolism (35.0 mL O_2/kg/min), and so on.

Statistical analysis

The sample size was estimated to detect a difference between two means using VO_2max as the most pertinent variable. A difference greater than 5 mL/min/kg was considered clinically relevant [15]. To have an 80% power to detect, and assuming a variance of 32 mL and a 0.050 two-sided significance level, the minimum required sample size was 20 patients in each group. Statistical analysis was performed using the SPSS 21.0 statistical package (IBM, Chicago, IL, USA). The Kolmogorov–Smirnov test confirmed the abnormal distribution of some of the variables. This required the use of the nonparametric Mann–Whitney test to compare the quantitative variables (Scheuermann vs. control group). The Z value was also calculated. The correlation between the magnitude of the thoracic kyphosis and the VO_2max/kg and thoracic kyphosis and VE of the Scheuermann group was analyzed. The probability level (p value) was considered statistically significant for values <.05.

Results

The study included a total of 41 patients with SK and 20 healthy participants as a control. There were no differences in the gender distribution of the two groups. Table 1 shows

Table 1
Anthropometric characteristics and maximal kyphosis magnitude of the healthy subjects and patients with Scheuermann hyperkyphosis

	Healthy (n = 20)		Scheuermann (n = 41)		Mann–Whitney test	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Z	p
Age (y)	13.9 ± 1.1	13.4–14.5	14.3 ± 7.7	14.1–14.5	−1.531	0.126
Weight (kg)	57.1 ± 4.5	54.9–59.1	59.5 ± 7.1	57.3–61.8	−1.771	0.077
Height (cm)	163.7 ± 4.5	161.6–165.8	168.1 ± 8.5	165.4–170.8	−2.129	0.033*
BMI (Kg/m^2)	21.3 ± 1.4	20.6–21.9	21.2 ± 3.4	20.2–22.3	−0.015	0.988
Maximal kyphosis (Cobb)			70.9 ± 9.2	68.1–73.9		

* p<.05.
** p<.01.

Table 2
Characteristics of the curves in patients with Scheuermann hyperkyphosis

	Spine levels	n (%)
Limits of the curve	T1–T12	1 (2.4)
	T2–L1	2 (4.8)
	T2–T12	20 (48.8)
	T3–L1	3 (7.3)
	T4–L1	8 (19.5)
	T4–T12	7 (17.1)
Apex	T6	14 (34.1)
	T7	16 (39.0)
	T8	7 (17.1)
	T9	4 (9.7)

the anthropometric characteristics of the two samples and the severity of the thoracic kyphosis. Mean age, weight, and BMI did not show statistically significant differences between the healthy subjects and patients with SK. However, individuals in the latter group were slightly taller than the controls ($p<.05$).

Table 2 shows the characteristic of the kyphotic curves in SK patients. The most common curve comprised T2-T12 levels (48.8%), with apex at T7 level (39.0%).

Table 3 discloses the cardiac, metabolic, and ventilator results obtained during the CPET. Regarding cardiovascular parameters, patients with hyperkyphosis started the test with higher average heart rates ($p<.01$) and reached exhaustion with lower average heart rates ($p<.05$) than did healthy controls. At maximal exercise, the average systolic BP was slightly higher in Scheuermann patients than in healthy subjects ($p<.05$). The decrease in $SatO_2$ at exhaustion was higher in individuals with hyperkyphosis than in healthy controls ($3.5 \pm 2.5\%$ versus $1.9 \pm 1.4\%$; Mann–Whitney test, Z:−2.328; p = .01). However, PuO_2, a relation between oxygen uptake and heart rate, was similar in both groups.

The maximal aerobic power, expressed by the body weight normalized VO_2max, was greater in healthy controls than in hyperkyphotic patients (50.0 ± 6.7 vs. 43.4 ± 11.3 mL/kg/min; $p<.05$), but there were no differences in the total VO_2 maximal volume (Table 3). There was an inverse correlation between the increase in magnitude of the thoracic kyphosis and the deterioration of the maximal aerobic power (Fig. 1).

The mean ventilatory capacity at maximal exercise, measured by VEmax, was slightly higher in hyperkyphotic individuals, but the results were not statistically significant (Table 2). In the SK group, 9 cases (21.9%) exhibited VE values >48 L/min, considered under the lower limit of normality [13,14]. None of the healthy controls had VE max values below that limit (Fisher's exact test, $p<.05$). In hyperkyphotic females, the VEmax values were inversely correlated with the severity of the thoracic kyphosis (Fig. 2). This correlation did not apply for males. When

Table 3
Results of the tolerance exercise test in healthy controls and patients with Scheuermann thoracic hyperkyphosis

	Exercise tolerance test		Mann–Whitney test	
	Healthy	Scheuermann		
Variables	Mean ± SD	Mean ± SD	Z	p
Cardiovascular				
HR basal	100.2 ± 13.2	112.8 ± 17.1	−2.831	0.005**
HR max	191.1 ± 8.5	186.8 ± 13.2	−2.070	0.038*
Syst. BP	113.7 ± 7.7	117.8 ± 11.5	−0.972	0.331
Syst. BP max	146.0 ± 13.2	153.0 ± 13.2	−2.101	0.036*
Sat O_2 basal	97.5 ± 0.8	97.4 ± 1.5	−0.359	0.720
Sat O_2 final	95.6 ± 1.6	93.9 ± 2.5	−2.593	0.009**
PuO_2, mL/min/bpm	15.2 ± 3.3	15.1 ± 4.9	−0.430	0.667
Metabolic				
VO_2 max mL	2883.0 ± 531.2	2820.1 ± 876.2	−0.592	0.554
VO_2 max/kg	49.9 ± 6.7	43.4 ± 11.3	−2.792	0.005**
VCO_2	2.9 ± 0.5	3.4 ± 1.1	−2.436	0.015*
R	1.10 ± 0.05	1.21 ± 0.08	−4.308	0.000**
Ventilatory				
FEV1	3.9 ± 0.8	4.3 ± 1.0	−1.560	0.119
VE	64.7 ± 8.9	67.2 ± 17.8	−1.521	0.128
VE/VCO_2	20.7 ± 2.4	19.5 ± 1.9	−2.444	0.015*
Efficiency				
VE/VO_2	22.9 ± 3.9	24.3 ± 3.2	−1.890	0.059
HR/VO_2	68.9 ± 15.7	74.2 ± 31.7	−0.430	0.667

SD, standard deviation; SE, standard error; HR, heart rate; BP, blood pressure; PuO_2, pulse of oxygen; VO_2 max, oxygen uptake at maximal exercise; VCO_2, carbon dioxide production; R, rate of gas exchange; VE, ventilation; VE/VCO_2, respiratory equivalent carbon dioxide; VE/VO_2, ventilatory efficiency; HR/VO_2, cardiovascular efficiency.

* $p<.05$.

** $p<.01$.

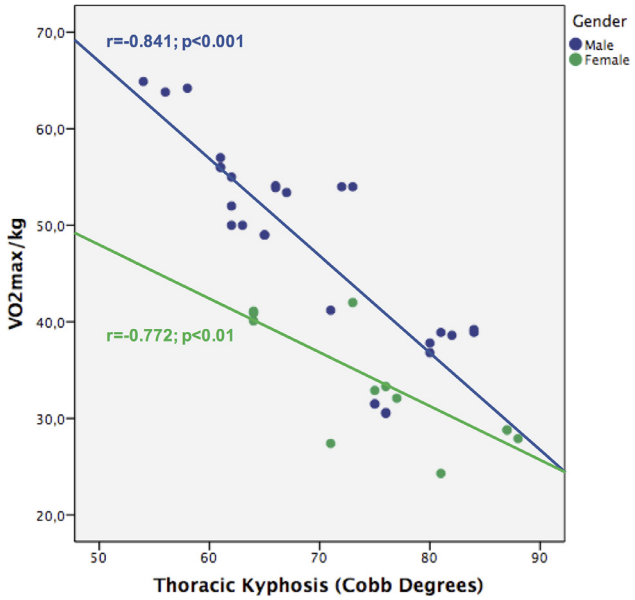

Fig. 1. Correlation between the increase in magnitude of the thoracic kyphosis and the deterioration of the maximal aerobic power in patients with Scheuermann thoracic hyperkyphosis.

ventilatory efficiency was considered using the VE/VO_2 ratio, both groups exhibited mean values that indicated an efficient ventilation pattern.

Table 4 displays the results of the exercise tolerance test in healthy controls and patients with Scheuermann kyphosis according to gender. Males with hyperkyphosis differed from healthy controls in some parameters: higher basal heart rates, higher BP at maximal exercise, greater VCO_2, VE/VO_2 ratios, and respiratory coefficients. Females with hyperkyphosis differed from their healthy counterparts in other parameters: lower HR, slightly higher $SatO_2$, and greater oxygen uptakes (all three at maximal exercise).

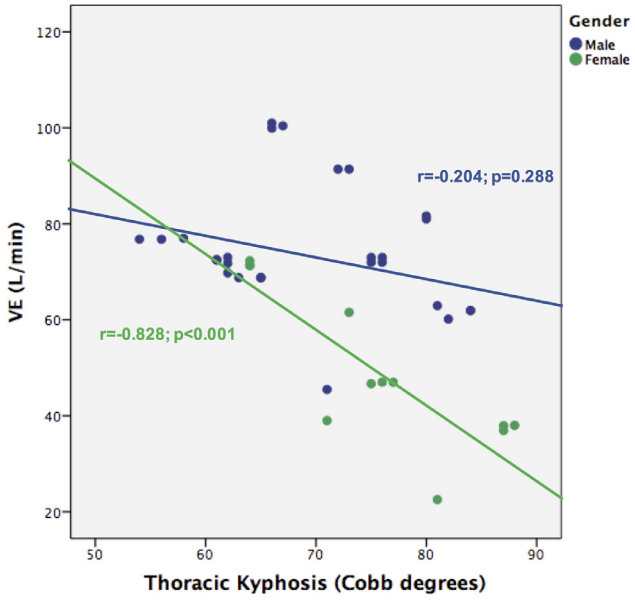

Fig. 2. Correlation between the increase in magnitude of the thoracic kyphosis and the ventilation at maximal exercise (VE) in patients with Scheuermann thoracic hyperkyphosis.

Analyzing cardiovascular, ventilatory, metabolic, and respiratory efficiency parameters by stratifying the sample of patients with Scheuermann kyphosis according to the magnitude of the hyperkyphosis revealed some interesting findings (Table 5). Patients with more severe hyperkyphosis (>75°) were seriously disturbed in their cardiorespiratory function, showing a decline in O_2 saturation at maximal exercise compared to patients with less than 75° of kyphosis. The oxygen pulse was consequently decreased in these severe hyperkyphotic patients. VO_2max and VEmax were severely deteriorated in patients with more than 75° of kyphosis. Aerobic maximal power impairment was already present in cases with hyperkyphosis between 65° and 75° (VO_2max/kg: 44.5 ± 9.9 mL/kg/min) and was severe in cases with more than 75° of kyphosis (33.3 ± 5.0 mL/kg/min) (Kruskal–Wallis test, $p<.001$). Patients with more severe thoracic kyphosis also showed impairment in their cardiovascular efficiency as measured by the HR/VO_2 quotient (Table 5).

This deterioration in cardiorespiratory function in relation to the severity of the thoracic hypokyphosis resulted in a limited tolerance for the exercise test that was reflected in the duration of the exercise test and the energy cost measured in METS (metabolic equivalents of task). Fig. 3 shows the differences between healthy controls and the three groups of hyperkyphotic patients concerning these two parameters: duration of the exercise test and MET consumption. Both parameters showed statistically significant differences between groups according to a nonparametric Kruskal–Wallis test (Table 5).

Discussion

This study is the first to describe cardiorespiratory functional limitations in a relatively large series of adolescent patients with SK underdoing a maximal CPET. As has been shown in AIS patients, CPET has the ability to amplify the small restrictions of the respiratory function that are often undetectable at rest by conventional spirometry, and do not affect ventilatory capacity for daily activities [3]. During a maximal exercise tolerance test, the demands of pulmonary function are severely increased as physical work is intensified, becoming therefore clearly apparent the respiratory limitations. This is the value of CPET, a more refined method than basal spirometry to assess in more detail the respiratory function.

According to our results, SK patients do not exhibit pulmonary restrictions in baseline static conditions compared to age-matched healthy individuals. However, patients with severe hyperkyphosis (>75°) showed respiratory intolerance to maximal exercise expressed by a lower aerobic power and shorter duration of the CPET compared to the healthy controls or patients with mild to moderate hyperkyphosis. This respiratory functional impairment was related

Table 4
Results of the tolerance exercise test according to gender in the two samples of individuals

	Males				Females			
	Healthy n = 12	Scheuermann n = 29	Mann–Whitney test		Healthy n = 8	Scheuermann n = 12	Mann–Whitney test	
Variables	Mean ± SD	Mean ± SD	Z	P	Mean ± SD	Mean ± SD	Z	p
Cardiovascular								
HR basal	112.6 ± 12.3	112.9 ± 18.9	−2.911	0.004**	110.2 ± 3.6	93.5 ± 13.2	−1.199	0.231
HR max	175.8 ± 7.0	191.4 ± 12.4	−1.191	0.234	198.0 ± 2.3	186.6 ± 8.1	−3.724	0.000**
Syst. BP	111.7 ± 7.5	120.3 ± 11.9	−1.286	0.199	113.1 ± 9.2	114.2 ± 7.0	−0.355	0.723
Syst. BP max	138.3 ± 7.8	159.1 ± 9.7	−2.626	0.009**	143.1 ± 10.3	147.9 ± 14.9	−1.058	0.290
Sat O_2 basal	96.7 ± 2.2	97.7 ± 1.0	−1.409	0.159	97.9 ± 0.6	97.3 ± 0.9	−1.326	0.185
Sat O_2 final	92.0 ± 2.2	94.7 ± 2.3	−1.539	0.124	95.4 ± 1.68	95.8 ± 1.5	−2.800	0.005**
PuO_2, mL/min/bpm	16.8 ± 4.6	17.1 ± 2.6	−1.003	0.316	12.4 ± 3.0	15.1 ± 4.9	−1.003	0.316
Metabolic								
VO_2 max mL	1940 ± 564	3184 ± 709	−0.774	0.439	2448 ± 361	3173 ± 417	−2.122	0.034*
VO_2 max/kg	33.3 ± 6.2	47.6 ± 10.3	−1.491	0.136	44.6 ± 2.3	53.5 ± 6.3	−3.474	0.001**
VCO_2	2.2 ± 0.6	3.8 ± 0.8	−3.671	0.000**	2.6 ± 0.2	3.2 ± 0.4	−1.506	0.132
R	1.19 ± 0.07	1.21 ± 0.08	−3.776	0.000**	1.12 ± 0.04	1.09 ± 0.05	−1.897	0.058
Ventilatory								
FEV1	3.3 ± 0.7	4.8 ± 0.7	−1.922	0.055	3.8 ± 0.2	4.1 ± 1.0	−1.312	0.190
VE	49.3 ± 16.3	74.7 ± 12.5	−1.750	0.080	57.2 ± 5.6	69.7 ± 6.9	−1.390	0.165
VE/VCO_2	20.9 ± 1.7	18.9 ± 1.7	−1.319	0.187	22.2 ± 1.6	19.8 ± 2.5	−1.471	0.141
Efficiency								
VE/VO_2	22.2 ± 2.6	23.8 ± 2.6	−2.178	0.029*	24.3 ± 3.2	25.7 ± 4.2	−0.694	0.487
HR/VO_2	59.9 ± 10.4	63.0 ± 14.7	−1.003	0.316	82.5 ± 12.3	101.3 ± 44.6	−1.003	0.316

SD, standard deviation; SE, standard error; HR, heart rate; BP, blood pressure; PuO_2, pulse of oxygen; VO_2 max, oxygen uptake at maximal exercise; VCO_2, carbon dioxide production; R, rate of gas exchange; VE, ventilation; VE/VCO_2, respiratory equivalent carbon dioxide; VE/VO_2: ventilatory efficiency; HR/VO_2, cardiovascular efficiency.

* p<.05.

** p<.01.

Table 5
Parameters of the tolerance exercise test showing relevant changes according to the severity of the hyperkyphosis

		Scheuermann (Maximal thoracic kyphosis)				
	Normokyphotic n = 20	<65° n = 13	65°–75° n = 14	>75° n = 14	Kruskal–Wallis test	
Variables	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Chi-square	p
Exercise efficiency						
Exercise test duration (min)	11.3 ± 2.3	10.9 ± 1.2	10.2 ± 1.4	8.9 ± 0.5**,‡	20.775	0.001
METS (1 = 3.5 mL O_2/kg/min)	13.9 ± 1.8	15.3 ± 2.2	12.7 ± 2.8	9.6 ± 1.4**,‡	29.365	0.001
Cardiovascular						
Decrease in Sat O_2	1.9 ± 1.4	2.5 ± 2.9	3.6 ± 1.9	4.2 ± 2.3	10.023	0.018
PuO_2, mL/min/bpm	15.2 ± 3.2	15.8 ± 1.6	17.5 ± 6.6	12.1 ± 3.5*,‡	9.850	0.020
Metabolic						
VO_2 max/kg	49.9 ± 6.7	53.1 ± 8.6	44.5 ± 9.9	33.3 ± 5.0**,‡	29.257	0.001
Ventilatory						
FEV1	4.1 ± 0.6	4.7 ± 0.4	4.6 ± 1.3	3.6 ± 0.8*,‡	14.161	0.003
VE	64.7 ± 8.9	72.8 ± 2.5	73.4 ± 20.9	56.0 ± 18.1*,†	12.800	0.005
Efficiency						
HR/VO_2	68.9 ± 15.6	63.7 ± 6.5	65.0 ± 25.0	93.1 ± 43.0*,‡	9.850	0.020

SD, standard deviation; METS, Metabolic equivalents of tasks; PuO_2, pulse of oxygen; VO_2 max, oxygen uptake at maximal exercise; VE, ventilation; HR/VO_2, cardiovascular efficiency.

Comparing to the subgroup of hyperkyphosis 65°–75°:

Comparing to the subgroup of hyperkyphosis <75°:

* p<.05.

** p<.01.

† p<.05.

‡ p<.01.

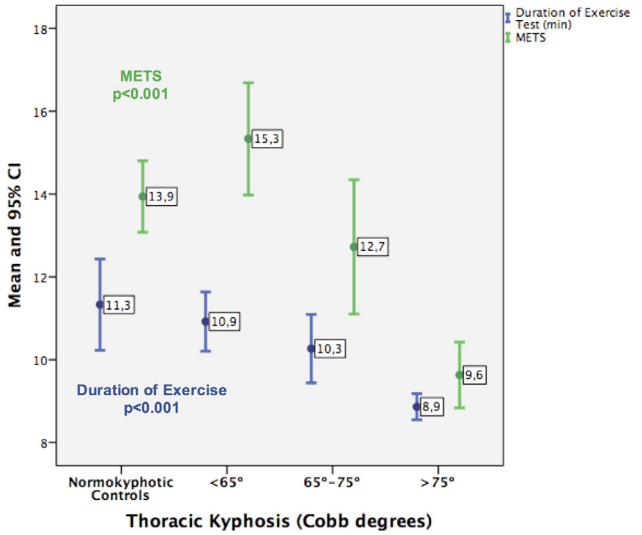

Fig. 3. Duration of the exercise test and the required metabolic equivalents of task (METS; 1 = 3.5 mL O_2/kg/min) in healthy controls and patients with Scheuermann disease stratified according to the magnitude of the hyperkyphosis.

to ventilatory restriction and inefficiency at maximal exercise.

The pulmonary function in patients with SK has been poorly studied. To our knowledge, there are only two previous reports describing the impact of Scheuermann hyperkyphosis on pulmonary function [5,7]. Researchers in both studies analyzed pulmonary function with basal spirometry and found restrictive lung disease in adult patients with kyphosis greater than 90°. Both studies also showed that the percentage of patients with moderate to severe functional respiratory impairment was higher at higher ranges of kyphosis magnitude. Using a slightly different stratification range, our findings confirm the previous results of Murray et al. [5] and Abbi et al. [7] concerning the deterioration of pulmonary volume in SK with severe curves (>75°). Regarding functional respiratory deterioration, there were no cases of severe impairment (<50% of predicted FEV1) in our series.

Few previous studies have evaluated the effects of hyperkyphosis on airway restriction, and most of those that have focus on the osteoporotic older spine, particularly in women [16–18]. In these osteoporosis-related kyphotic patients, pulmonary compromise was associated with multiple factors, including kyphosis angle, level of the kyphosis apex, and number of involved vertebrae. In the Harrisson et al. [19] series, pulmonary function was significantly compromised when kyphosis angle was greater than 55°. Even in congenital kyphosis and/or kyphoscoliosis, more than half of the investigated patients exhibited different grades of respiratory function compromise [20]. In these cases, the severity of respiratory impairment was associated with the degree of kyphosis.

Considering only baseline respiratory parameters, some of our Scheuermann patients with light or moderate curves (<75°) had higher average values than did healthy controls for some pulmonary function parameters. In other words, slightly or moderately hyperkyphotic patients with Scheuermann kyphosis showed normal or above-normal expected values in their respiratory function. A feasible explanation for this finding is the increased longitudinal dimension of the thorax in nonsevere hyperkyphosis, which could be responsible for a functional increase in chest volume. This finding is also in accordance with our baseline data, in which compared to control subjects, patients with less than 75° kyphosis disclosed an average increase of 422 mL in FVC.

Ventilatory restrictions during maximal exercise at different stages of thoracic kyphosis in adolescent patients have not been described so far. In our series, 18 of the 41 patients with SK (43.9%) had VO_2max scores below the 40 to 50 mL/kg/min range, which is the expected result for adolescents who are not engaged in regular aerobic training [21]. In 12 patients, the VO_2max values were below 35 mL/kg/min, indicating an extremely low tolerance to exercise that was related to a greater magnitude of kyphotic curvature. Furthermore, the VEmax scores of 9 Scheuermann cases (22%) were below the expected values for healthy adolescents (range, 50–90 L), indicating ventilatory limitation at maximal exercise.

According to our findings, there is a relationship between the magnitude of thoracic kyphosis and both aerobic capacity and ventilation. VO_2max values decrease as hyperkyphosis increases. The decrease in VO_2max was evident in the two groups with moderate and severe hyperkyphosis, the latter showing extremely low VO_2max values. In addition, VEmax exhibited a correlation with the magnitude of hyperkyphosis, also showing an increase in the slight and moderate hyperkyphosis groups compared to healthy controls and greatly decreasing in hyperkyphotic cases with more than 75°. These findings are in accordance with the inverse correlation observed in the current study between the magnitude of the hyperkyphosis and the basal FEV1 (r: −0.506; p<.001), reflecting the restrictive influence that hyperkyphosis has on ventilatory mechanisms.

In severe hyperkyphotic patients with SK, restrictive ventilatory impairment due to a reduced thoracic volume is a probable mechanism for explaining the effect of increasing kyphosis severity on declining pulmonary function. Katzman et al. [22] found that men with worse kyphosis have a lower spinal muscle density than men with less thoracic curvature. Both excessive kyphosis and muscle weakness may disrupt the thoracic cage mechanics and lead to reduced lung function. In brief, mechanical limitations on the respiratory system imposed by hyperkyphosis, such as reduced inspiratory muscle strength and abnormal shape and movement of the rib cage, could explain these ventilation abnormalities during exercise. The overall structural stiffness of the chest cage and the spine imposed by the SK may contribute to the mechanical inefficiency and impairment of pulmonary function found in these patients.

The role of the diaphragm in the respiratory function has been considered of crucial importance [23]. The hyperkyphotic thoracic deformity of patients with SK could increase the abdominal pressure, limiting therefore the functionality of the diaphragm, that is, impairing its ability to expand the lower rib cage. This mechanism has been previously analyzed in patients with hyperkyphosis in which inspiratory muscle strength was clearly reduced [24]. However, no correlation was found between inspiratory muscle function and spine deformity. In any case, the dysfunction of the diaphragm could be considered, at least, an additional factor behind the respiratory functional restriction detected in this group of patients.

In young patients, severe kyphosis may not only compress the lungs, which directly leads to restrictive ventilation function, but can also affect the development of alveoli and capillary vessels, which further affects oxygenation. Furthermore, over time, it has been observed that patients with thoracic hyperkyphosis are prone to experience multiple episodes of acute respiratory failure or chronic respiratory failure requiring prolonged ventilatory support [25,26]. Recently, data regarding respiratory events requiring hospitalization and poor prognosis have been reported in patients with thoracic hyperkyphosis who did not undergo corrective surgery [27]. Since the severity of the kyphosis angle was correlated with respiratory insufficiency, surgical correction may be desirable and therefore indicated in young patients to prevent respiratory impairment due to severe curve progression. However, this was not investigated in the current study.

This study has some limitations that include the limited number of Scheuermann patients with severe hyperkyphosis (>75°). This series may therefore underrepresent individuals with the most severe kyphosis and/or pulmonary restrictions. A second limitation is the variability of measuring pulmonary function accurately during a maximal exercise tolerance test. This limitation is inherent to all studies measuring oxygen uptake at maximal exercise. A third limitation is that the diaphragmatic function was not analyzed. The thoracic vertebral disposition of patients with SK could increase the abdominal pressure on the diaphragm, limiting its functionality. This mechanism could be considered at least as an additional factor behind the respiratory restriction presented by this group of patients. However, the evaluation of the diaphragm function requires, at least, semi-invasive technology. Finally, the Scheuermann patients were slightly taller than the control patients but also slightly older (6 months). At these ages, small differences in age (only a few months) can explain small differences in height but not in respiratory function.

In summary, these results indicate that patients with mild or moderate hyperkyphosis do not exhibit baseline pulmonary restrictions, and they have a similar tolerance to maximal exercise as healthy controls have. Most patients with more severe hyperkyphosis (>75°) show baseline respiratory limitations and, subsequently, intolerance to maximal exercise as expressed by reduced aerobic power and a shorter duration of the exercise test, both of which are related to ventilatory restriction and respiratory inefficiency at maximal exercise. Maximal oxygen uptake and ventilation parameters are strongly related to the magnitude of the thoracic kyphosis, with higher restrictions in curves surpassing 75° Cobb.

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