



Effects of inspiratory muscle training on respiratory muscle strength, respiratory function and functional capacity in adolescents with idiopathic scoliosis

A randomized, controlled trial

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Summary

Background Adolescent Idiopathic Scoliosis (AIS) may impair respiratory dynamics and affect the performance of inspiratory and expiratory muscles. The benefit of inspiratory muscle training (IMT) is not well investigated in AIS. We aimed to investigate the effects of IMT on respiratory muscle strength, respiratory function and functional capacity in adolescents with mild to moderate AIS.

Methods Thirty-six adolescents were randomized into control or IMT groups. Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1) and peak expiratory flow (PEF) were measured by spirometry; respiratory muscle strength by maximum inspiratory pressure (MIP) and maximum expiratory pressure

(MEP); and functional capacity by 6-min walk test (6MWT) before and after the 8-week-long home-based exercise program. Both groups received conventional exercise program including diaphragmatic breathing exercises, resistive local expansion exercise on the collapsed areas in concave sides of scoliosis, spinal stabilization, strengthening of interscapular muscles and stretching exercises. IMT group also trained with Threshold IMT device for 15 minutes, twice a day for 8 weeks at the intensity of 30% of initial MIP value in addition to conventional exercise program.

Results FEV1, PEF, MIP, MEP and 6MWT distance significantly improved in both groups. IMT group also showed significant improvement in FVC. The increases in FVC, MIP, MEP and 6MWT distance of IMT group were significantly higher compared to control group.

Conclusion IMT is found to be beneficial for patients with AIS for achieving further improvements in respiratory function, respiratory muscle strength and functional capacity compared to conventional exercise program alone.

Keywords Spine deformity · Children · Respiratory muscle training · Pulmonary function · Exercise capacity

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Introduction

Scoliosis is defined as a lateral flexion of the spine with a curve greater than 10° in the anteroposterior radiograph [1]. Scoliosis is a three dimensional (3D) structural deformity involving a curvature in the coronal plane, a change of curves in the sagittal plane, and a rotation in the transverse plane [2]. Adolescent idiopathic scoliosis (AIS) is the most common type of scoliosis with an incidence of 2% in the general popu-

lation [2–4]. This 3D deformity also results in various respiratory dysfunctions in scoliosis patients. In this context, the disease is accompanied by a decreased respiratory function, inadequate functional capacity and low respiratory muscle strength [3–5].

The relationship between scoliosis and altered respiratory function has long been known and studied in the literature [6]. The AIS has also been known with physically deconditioning in the literature for a long time [7]. Impairment of respiratory function and functional capacity observed in AIS patients are suggested to depend on the size of spinal curvature, vertebral rotation, thoracic kyphosis and lordosis, and chest deformation [8–10]. Furthermore, there are studies which support the theory that muscle dysfunction might be the cause and not the consequence of AIS. They suggested that AIS could be a primary and systemic muscle disorder, which might have led to both spinal deformity and generalized muscle dysfunction; however, more studies are needed to prove such a challenging hypothesis [11].

From a literary perspective, a significant proportion of the conservative treatment of scoliosis consists of applications to increase the respiratory function and functional capacity by exercise training [1, 12]. Assessing pulmonary function, identifying the respiratory problems of patients with scoliosis, and adding respiratory exercises to the treatment program have great importance for the rehabilitation of patients [13–16]. The European Respiratory Society (ERS) consensus recommends inspiratory muscle training (IMT) in association with a routine pulmonary rehabilitation program for patients with inspiratory muscle weakness [17]; however, the impact of IMT performed during rehabilitation of AIS has not been demonstrated yet. In this respect, as AIS has also been accompanied with respiratory muscle weakness [3, 6, 11, 18–20], a randomized controlled study was conducted to elucidate the effects of IMT on respiratory muscle strength, respiratory function and functional capacity of female adolescents with mild to moderate scoliosis.

Material and methods

Study population

A total of forty-two patients referred from the department of orthopedics and traumatology and diagnosed with mild or moderate AIS according to the Scoliosis Research Society criteria [21] by the orthopedic surgeon to the physiotherapy and rehabilitation department of a university were assessed for eligibility.

The selection criteria of the participants were that the age range should be between 10–18 years, thoracic and lumbar Cobb's angle, the degree of the spinal curvature, measured directly in the radiography should be 20–50°, without treatment experience before and any orthopedic problems other than scoliosis. Exclusion criteria were neuromuscular diseases, mental

problems which may affect cooperation, any chronic upper respiratory diseases affecting the test results and any orthopedic problem affecting the mobility of any previous musculoskeletal surgical intervention.

Of the thirty-six patients who met the inclusion criteria and were routinely admitted to the rehabilitation program were randomized into the control and IMT groups using a numbered series of 36 prefilled envelopes specifying group assignments generated by a computer-based program. Patients were unaware of group assignments. Assessments and treatment programs were applied by different physiotherapists. The assessor was blinded to group assignments. The control group followed a predefined standardized home-based exercise program without IMT, while the IMT group followed the same standardized exercise program combined with IMT 6 days per week for 8 weeks. All patients came to the clinic once per week for supervised exercise sessions according to their group.

All patients and their parents were informed about the study in detail and signed the written informed consent. The study was approved by the Ethics Committee of Bezmialem Vakif University (Approval no: 9/91) and supported by the Scientific Project Unit of Bezmialem Vakif University (Project Number: 12.2016/29). Study was registered at www.ClinicalTrials.gov with identifier number of NCT03391895 before the data collection began.

Assessments

During the first visit of the patients, an orthopedic surgeon measured thoracic and lumbar Cobb angles (°). For measurement of the Cobb angle, two lines were drawn parallel to the end plates of the vertebral bodies at the beginning and at the end of the curve in the anteroposterior projection. Subsequently, third and fourth lines were drawn perpendicular to each of the first two lines to define the Cobb angle [11].

Spirometric pulmonary function test (PFT) was applied by using a spirometer device (Pony FX Spirometer; COSMED, Rome, Italy) [22] according to the criteria of the American Thorax Society (ATS) and ERS [23] and forced vital capacity (FVC), forced expiratory volume in 1s (FEV1) and peak expiratory flow (PEF) were measured and expressed as the percentages of the predicted values [24].

Respiratory muscle strength, as maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP), were measured by a portable, noninvasive, electronic mouth pressure device (MicroRPM; Micro Medical London, United Kingdom) [25] according to the criteria of the ATS and ERS [26].

Functional capacity was evaluated by the 6-min walk distance (6MWD), calculated by using the 6-min walk test (6MWT) according to the criteria of ATS [27] and recorded in meters.

The author who applied the assessments was blinded to group assignments. All devices used were

calibrated beforehand. All measurements were applied before and after the 8-week rehabilitation program, except MIP. MIP was additionally measured once a week in all patients when they came to the clinic for the weekly supervised session. The training intensity in the IMT group was adjusted each week according to the new MIP measurements. Thus, to eliminate learning effect on MIP measurements, the control group was also assessed for MIP once a week as for the IMT group.

Intervention

After the initial evaluation, all patients were given a home-based exercise program by a physiotherapist, consisting of deep diaphragmatic respiratory exercises, resistive respiratory exercises to weak zones on the concave sides of the scoliosis performed by expanding the concave parts of the curve through deep inspiration against the resistance of an elastic exercise band covering the chest of patients diagonally [28], spinal stabilization exercises [29], strengthening of interscapular muscles and stretching exercises. Spinal stabilization exercises are performed according to the study by Monticone et al. as the exercises were designed for strengthening deep spinal muscles while maintaining self-correction and segmentary stretching involving the limbs and back muscles [29]. Patients in both groups have performed the exercises as 10 repetitions once a day. Contents of the home-based program was created so that the duration of the exercise session lasts 45 min. Patients were provided with a brochure containing the exercises in the home-based program (supplementary file).

In the IMT group, the same home-based exercise program was combined with IMT, performed with the Threshold IMT device® (Philips, Amsterdam, Netherlands), for 15 min per set and twice per day. During patient's weekly visit to the clinic for a supervised exercise session, 30% of the newly measured MIP value was identified as the new training workload.

All patients trained for 6 days a week for 8 weeks. One session in each week was supervised in the clinic by a physiotherapist. The rest of the sessions were performed at home. Patients were instructed to keep a diary for home sessions to improve adherence to exercise program.

Patients' diaries were inspected weekly, and the program adherence was calculated at the end of the training program for both groups. Program adherence (%) was calculated as the ratio of the completed sessions to total sessions (total = 48 sessions) multiplied by 100. In addition, program adherence was compared between the IMT and control groups.

Sample size

In the literature there has not been any study evaluating the effect of IMT on the findings of 6MWT of the

adolescents with AIS, which has the highest standard deviation among the variables of interest in our study.

Thus, the normative value for 6MWD in AIS children was considered as 400 ± 49 m [15] and the expected sample size was calculated as 30 patients in order to detect a minimum clinically significant change of 54 m calculated for children with cerebral palsy in the same age group of this test [30], at a confidence interval of 95% with a power of 80%. Considered potential drop-out during the study, the sample size was increased by 20% and 36 patients were included in the final cohort.

Statistical analysis

All statistical tests were performed using SPSS V20.0 statistical program (IBM Corp., Armonk, N.Y., USA). Normality distribution was determined by Kolmogorov-

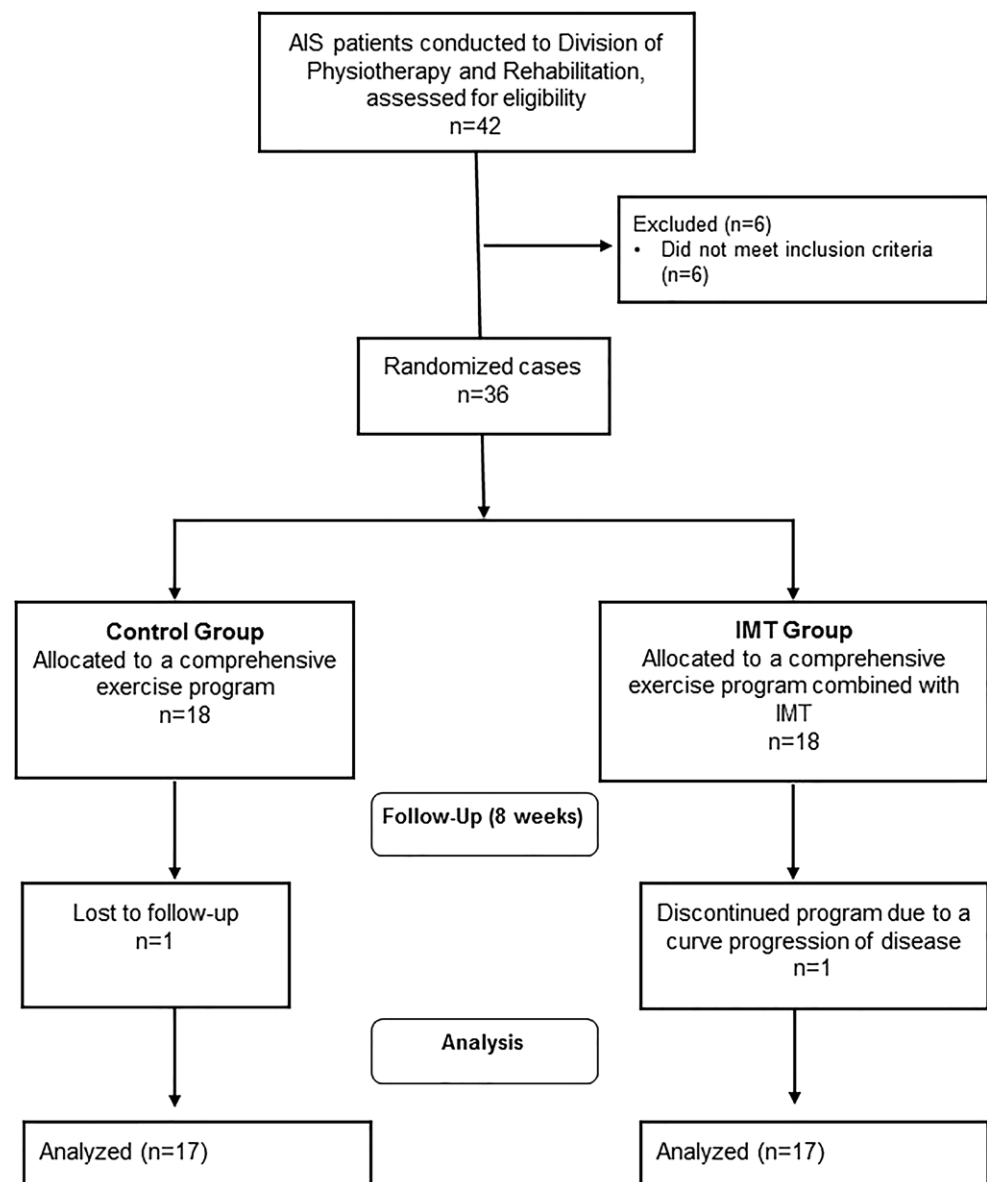
Smirnov test. As the data were normally distributed, continuous variables were expressed as mean $\pm$ SD. Baseline values of groups were compared using independent samples T-test. The χ^2 -test was used to compare the distribution of scoliosis type between groups. Pretraining and posttraining data were compared using paired samples t-test for each group. A mixed ANOVA (repeated measures ANOVA with between-subjects factor) was used to analyze whether the effects of interventions differ between groups. A p -value of <0.05 was considered as statistically significant.

Results

A total of 42 mild to moderate AIS patients were included to our study. After verification of eligibility criteria, six patients who did not meet inclusion criteria, i.e. two patients due to the older age and four patients with higher scoliosis curve, were excluded from the study. The 36 patients were randomized into the control group ($n=18$) or the IMT group ($n=18$). The control group received a comprehensive exercise program and the IMT group received the same exercise program combined with IMT. Among these randomized cases two patients were excluded from the study and the total number of patients analyzed at the end of exercises was 34 (Fig. 1). Program adherence averaged $98.3\% \pm 5.2\%$ in the IMT group and $97.8\% \pm 4.7\%$ in the control group, which was not different between the groups ($p=0.764$). Reasons for missing one or more sessions were patient's refusal and/or school examinations.

As reported in Table 1, demographic and clinical features and baseline values (age, height, arm span, weight, body mass index and Cobb's angle) of the patients were comparable between control and IMT groups ($p>0.05$). Moreover, the baseline percentages of FEV1, FVC, FEV1/FVC and PEF values, baseline values of MIP, MEP and 6MWD were compared between the control and training groups, and no signif-

Fig. 1 Flow chart of participants



icant difference was found ($p > 0.05$). The patients in both groups did not differ in terms of type of scoliosis ($p > 0.05$). The most common type of scoliosis was the double major and the least one was thoracic type of scoliosis.

The mean results of PFT of all patients were in the normal physiological range although only three patients in the control group and two patients in IMT group (a total of five cases; 13.5%) showed a mild restrictive type of respiratory pattern.

Table 2 gives the results for comparative analysis of the exercise programs combined with or without IMT regarding the respiratory function, respiratory muscle strength and functional capacity of the patients. The PFT showed statistically significant improvements in the respiratory parameters including FEV1 (pred%) and PEF (pred%) in both control and IMT groups in comparison with the data from the beginning of exercises ($p < 0.05$). The MIP and MEP values in post-

exercise term were also improved significantly in both groups ($p < 0.05$). The IMT group also showed a significant improvement for the value of FVC (pred%) compared with the beginning value ($p < 0.05$) and 6MWD was also elevated markedly in both groups ($p < 0.05$).

The findings of the 8-week IMT training period revealed that the increases in FVC (pred%), MIP, MEP and 6MWD of the IMT group were found to be statistically higher than the increases in the control group ($p < 0.05$) but the changes in FEV1 (pred%) and PEF (pred%) showed no difference among groups.

Discussion

In this randomized controlled trial investigating the effects of a comprehensive exercise program combined with IMT in mild to moderate AIS children, the 8-week therapy was found to be effective in improving

Table 1 Comparative analysis of demographic features and baseline values of the patients

	Control group (<i>n</i> = 17)	IMT group (<i>n</i> = 17)	<i>P</i> -value
Gender (male/female)	0/17	0/17	1.000
Age (years)	13.9 ± 1.83	13.7 ± 1.8	0.708
Height (cm)	159 ± 7.81	155 ± 10.3	0.206
Arm span (cm)	161 ± 7.72	158 ± 10.6	0.308
Weight (kg)	49.8 ± 10.3	45.7 ± 10.8	0.264
BMI (kg/m ²)	19.4 ± 3.51	18.7 ± 3.07	0.514
Thoracic Cobb angle (°)	23.8 ± 13.7	22.8 ± 11.4	0.808
Lumbar Cobb angle (°)	24.2 ± 11.0	21.2 ± 11.6	0.436
<i>Scoliosis type</i>			
Thoracic	1 (5.9)	1 (5.9)	0.976
Lumbar	5 (29.4)	5 (29.5)	
Thoracolumbar	3 (17.6)	4 (23.5)	
Double major	8 (47.1)	7 (41.2)	
Data are given as mean ± standard deviation or <i>n</i> (%) <i>IMT</i> inspiratory muscle training, <i>BMI</i> body mass index			

respiratory muscle strength, functional capacity and respiratory function.

Most of AIS patients were reported to have respiratory functional defects frequently with a restrictive type of respiratory disorder [11]. The cardiorespiratory defects including a diminished lung capacity, respiratory muscle weakness and decreased exercise capacity are obviously serious complications of idiopathic scoliosis [11]. A deformed thoracic cage increases the stiffness of the chest wall and reduces the respiratory muscle strength, leading to a failure in mechanical function of the diaphragm [31]. In addition, a respiratory muscle weakness in AIS occurs because of abnormal configuration of the diaphragm. The torsion on the diaphragm may increase the radius of the curva-

ture of the diaphragm, thereby decreasing the force-generating capacity and making it less efficient [6].

The IMT is a training used to alleviate the symptoms of various chronic diseases such as COPD [32], cystic fibrosis [33], neuromuscular diseases [34], severe kyphoscoliosis [35] and cardiac diseases [36, 37] as well as increasing the muscle strength and functional capacity; however, there is no literature about the application of IMT in AIS cases, to the best of our knowledge. There are numerous studies reporting lower respiratory muscle strength in the scoliosis adolescents [3, 11, 20]. Therefore, it is hypothesized that IMT would have a positive effect especially on respiratory muscle strength and functional capacity, which is known to be lower in children with AIS than healthy age groups.

The mean results of PFT of all patients were in the normal physiological range although only three patients in the control group and two patients in IMT group (a total of five cases; 13.5%) showed a mild restrictive type of respiratory pattern, suggesting that the patients with AIS had a mild to moderate scoliosis (Cobb angle range 10°–45°) [3]. According to American Thoracic Society/European Respiratory Society (ATS/ERS), maximum inspiratory pressure below 80 cmH₂O indicates inspiratory muscle weakness [26], whereas the mean values of our patient groups were below this value. On the other hand, there is an age-matched cohort study by Abdelaal et al. (2018) about functional capacity of adolescents with mild and moderate scoliosis, reporting that 6MWD was lower in scoliosis adolescents than the age-matched healthy controls [38]; however, our pre-exercise 6MWD values were higher than the values in their adolescent group due to variation in sampling from different population and races. It may be considered that our scoliosis adolescents are functionally more active than their study population. As an age-matched example to

Table 2 Comparative analysis of the exercise programs combined with or without IMT on pulmonary function, respiratory muscle strength and functional capacity of the patients

Control group (n= 17)					IMT group (n= 17)				Between-group difference p value
	Pre-exercise	Post-exercise	Within-group difference (Δ)	Within-group p value	Pre-exercise	Post-exercise	Within-group difference (Δ)	Within-group p value	
Pulmonary Function									
FVC (pred%)	101.0 ± 13.9	104.0 ± 13.1	2.29 ± 5.71	0.117	95.2 ± 8.6	102.0 ± 10.4	6.76 ± 5.91	0.000*	0.043*
FEV ₁ (pred%)	94.1 ± 11.2	99.7 ± 11.2	5.29 ± 4.78	0.000*	90.8 ± 8.8	95.9 ± 11.1	5.06 ± 5.03	0.001*	0.890
PEF (pred%)	83.4 ± 22.2	106.0 ± 16.6	22.2 ± 12.9	0.000*	89.1 ± 13.5	107 ± 16.2	18.35 ± 9.7	0.000*	0.522
Respiratory Muscle Strength									
MIP (cmH ₂ O)	70.9 ± 16.2	91.8 ± 18.6	20.9 ± 7.03	0.000*	66.2 ± 15.9	111 ± 12.4	44.9 ± 11.9	0.000*	0.000*
MEP (cmH ₂ O)	75.7 ± 18.7	96.2 ± 16.4	20.5 ± 7.67	0.000*	76.9 ± 11.7	108 ± 11.5	31.6 ± 12.6	0.000*	0.005*
Functional Capacity									
6MWD (m)	638.0 ± 44.1	667.0 ± 47.3	28.5 ± 14.0	0.000*	613.0 ± 45.5	682.0 ± 38.9	69.1 ± 20.7	0.000*	0.000*
Data are given as mean ± standard deviation Predictive values of FVC, FEV1 and PEF were determined according to Quanjer et al. [24] IMT inspiratory muscle training, Δ the difference between pre and post-exercise values, FVC forced vital capacity, FEV1 forced expiratory flow in 1 s, PEF peak expiratory flow, MIP maximum inspiratory pressure, MEP maximum expiratory pressure, 6MWD 6-min walk distance *p< 0.05									

our study, Geiger et al. evaluated 6MWD for healthy children and 71 adolescents of a population-based sample. Median 6MWD increased from the age of 12 to 15 years, given as 663.0 ± 50.8 , which is statistically higher than our results (one sample t test, $p < 0.001$) [39].

Kumar et al. assessed the effect of task-oriented exercises based on ergonomics on the pulmonary function of 36 patients with AIS divided into experimental and control groups [40]. The subjects in the control group underwent spinal strengthening exercises, active self-correction and breathing exercises, whereas subjects in the experimental group followed task-oriented exercises based on ergonomics in addition to exercises for the conventional group for 1 year. At the end of the exercise program, pulmonary function was evaluated and a significant improvement was observed in experimental group rather than the control group, as the results of FVC, FEV1 and VC values in experimental group were higher than the control group. The task-oriented exercise protocol was found to be beneficial for patients with AIS, allowing a significant improvement of their pulmonary function [40]. Similarly, in our study, our patients of control and IMT groups were given a home-based exercise program by the physiotherapist, consisting of deep diaphragmatic respiratory exercises, resistive respiratory exercises to weak zones on the concave sides of the scoliosis, spinal stabilization exercises, strengthening of interscapular muscles and stretching exercises. As a result, FEV1, PEF and 6MWD were significantly increased in both groups compared with the baseline values, suggesting a global conditioning improvement indicated by PFT and 6MWD in AIS patients. Our IMT group showed significant increases in all parameters of PFT including FVC and 6MWD compared with the baseline values. Moreover, the increases in FVC and 6MWD were statistically higher than the control group.

According to ATS/ERS, FVC is limited by weakness of both the inspiratory muscles and expiratory muscles. In addition to the direct effect of loss of muscle force, reductions in compliance of both lungs and chest wall also contribute to the reduction in FVC of patients with respiratory muscle weakness. Thus, FVC reflects the combined effect of weakness and the static load on respiratory muscles [26]. Therefore, improvement in FVC in our study may be attributed to increases in the respiratory muscle strength through IMT. Moreover, in a meta-analysis by Plentz et al. it was reported that the increase in the strength of respiratory muscles delays the development of diaphragmatic fatigue, increases ventilatory efficiency and reduces the blood flow required by the respiratory muscles during exercise in patients with heart failure. As a result, sympathetic activation decreases, systemic vasodilation and perfusion of the peripheral muscles improves, thereby functional capacity increases [41]. The same mechanism may be providing an increase

in functional capacity in our patients with scoliosis, as well, after the 8-week IMT program.

A number of studies have reported a failure in the respiratory function [38] and decreased respiratory muscle strength [31] in mild to moderate AIS. Martínez-Llorens et al. assessed the lung and muscle function, together with exercise capacity in 60 patients with AIS with pronounced spinal deformity (Cobb angle $>40^\circ$) and found that the patients had only mild to moderate abnormal ventilatory patterns [11]. The function of respiratory and limb muscles and exercise capacity were under the normal limits in AIS patients. Most of the patients (91%) had a mild to severe reduction in exercise capacity. There appeared to be no connection between spinal deformity and lung function, muscle function or exercise capacity so they concluded that AIS patients show generalized muscle dysfunction which contributes to the reduction in their exercise capacity, even in the absence of severe respiratory impairment. In the present study, our baseline results of the respiratory muscle strength in AIS patients with normal respiratory function were lower than the findings of the healthy control group and predictive values of Martínez-Llorens et al. [11]. A study by Lanza et al. evaluated MIP and MEP values of 132 healthy adolescents with a mean age of 14 years according to criteria of ATS/ERS, and the MIP value was calculated as $95.2 \text{ cmH}_2\text{O}$, and the MEP value was $91.3 \text{ cmH}_2\text{O}$ [42]. These values were statistically higher than the respiratory muscle strength results of our study (one sample t test; $p < 0.001$).

These differences are still unknown but there are several different factors influencing and varying the muscle function in AIS patients [11]. Yet, our findings of PFT in our adolescent patients with mild or moderate ($12\text{--}45^\circ$) scoliosis can be considered in the general normal range although our baseline results of the respiratory strength were lower than the values of healthy adolescents [11]. According to ATS/ERS, a maximum inspiratory pressure below $80 \text{ cmH}_2\text{O}$ indicates inspiratory muscle weakness and in the case of respiratory muscle weakness, MIP is more sensitive than FVC values, because the relationship between FVC and MIP is curvilinear. Therefore, decreases in respiratory muscle strength occur before the decreases in lung volume [26]. This may be the reason why our patients had a decrease in the respiratory muscle strength, but not in the pulmonary function.

The applied exercise program, which includes spinal stabilization and 3D breathing exercises, was beneficial on the respiratory system of AIS patients treated with IMT as well as of the control group treated without IMT. Despite normal findings of the PFT, the slightly lower baseline functional capacity in our patients may be related to the dysfunction in respiratory muscles and/or general inactivity of AIS patients.

The reason for muscle dysfunction in AIS is unknown. Various factors such as nutritional status, de-

iciency in physical activities or systemic inflammation levels may affect muscular function; however, inspiratory muscles may be affected by the secondary mechanical forces elevated in the spinal deformities and respiratory defects in AIS patients [11]. There are a limited number of studies investigating the changes in respiratory muscle strength in AIS cases [20]. In fact, the results of PFT in these patients were not always varied, even found in normal ranges [43]; however, the reasons for reduced functional capacity and muscle strength in AIS patients still have been subject to many studies [3]. In a study by Alves et al., the impact of a physical rehabilitation program on respiratory function of 34 adolescents with severe AIS was investigated, a global conditioning improved after a 4-month rehabilitation program, expressed by PFT and 6MWT results [15], similar to our results. Baseline 6MWD of our study was higher than Alves et al. since the severity of scoliosis (Cobb angle 45°–88°) in their patients was higher than our study including the patients with mild to moderate scoliosis (Cobb angle range 10°–45°). Thus, the higher baseline value of 6MWD in our study is expected.

In another prospective randomized study by Alves et al., the impact of a physiotherapy protocol on MIP and MEP in patients with AIS ($n=90$) was analyzed and the respiratory muscle strength was evaluated before and after an 8-week treatment period [20]. In correlation to the findings of our study, a significant increase of MIP and MEP was shown in the group receiving physical therapy. It can be concluded that exercising via pulmonary rehabilitation is beneficial to patients with AIS, who have shown significant increases in respiratory muscle strength after exercise program.

As the respiratory disorder is not clinically apparent in AIS patients until irreversible changes in pulmonary function are observed, the PFT is suggested as a regular method for early diagnosis of this problem in the children with thoracic and thoracolumbar mild scoliosis [28]. In a randomized controlled study, the effects of Schroth three-dimensional exercises (SE) in combination with respiratory muscle exercise (RME) on pulmonary function were studied in 15 subjects with scoliosis. The experimental group underwent SE+RME treatment while the control group performed only the SE for 8 weeks [44]. The SE+RME group showed a significant improvement in pulmonary function compared to the state before training. The authors suggested that SE in combination with RME could be a more effective intervention for improvement of the pulmonary function for scoliosis patients. This study with limited number of subjects differed from our study by respiratory muscle training device instead of threshold IMT performed by our patients.

In the present study, IMT yielded further improvements in training group. As the inspiratory muscles, including the diaphragm, are morphologically and functionally skeletal muscles, they respond to train-

ing in the same way as any locomotor muscle would, if an appropriate physiological load is applied [45]. Thus, it is not surprising to gain improvements in inspiratory muscle strength with the appropriate training in terms of physiological effect of IMT on MIP and MEP values. Regarding how expiratory muscles are stimulated with inspiratory training to produce strength gains, only Souza et al. stated that the neural conditioning resulting from repeated exposures to the same task (also performing maximum expiration maneuvers as well as inspiration maneuvers during inspiratory muscle training) could generate increases in expiratory muscle strength by improving neuromuscular recruitment pattern [46].

This study has limitations that should be mentioned. First lack of our study is the evaluation of peripheral muscle strength. It is an important predictor of the general weakness of AIS patients and this disease is usually accompanied by disturbed skeletal muscle function; however, all of these factors were out of the scope of the current study. The main objective of this study was to assess the effect of IMT in AIS patients on pulmonary and functional aspects. The second limitation is the disproportion of gender (girl to boy ratio). The gender ratio in the current study does not reflect the global female/male ratio of AIS; however, the differences in pulmonary and functional responses to IMT between girls and boys were out of the scope of this study. Further studies are needed with inclusion of larger numbers of patients in order to overcome these limitations.

In conclusion, IMT is effective in improving the respiratory muscle strength, FVC and functional capacity in mild to moderate AIS cases although the patients have no respiratory dysfunctions arising from the potential natural course of the disease yet. In the absence of advanced respiratory impairment in the patients with scoliosis, the reduced respiratory muscle strength might be the primary respiratory symptom of scoliosis. In the light of findings obtained from the present study, IMT may be beneficial for preventing the weakness of the respiratory muscle strength, and the prognostic respiratory deficits developing in scoliosis.

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Declarations

Conflict of interest G. Basbug, H.N. Gurses, M. Zeren and N.M. Elmadag declare that they have no competing interests.

Ethical standards All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. The study was approved by Ethics Committee of Bezmialem Vakif

University (approval number: 9/91). Informed consent was obtained from all patients and their parents for being included in the study.

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