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RESEARCH

The effect of Pilates-based exercise applied with hybrid telerehabilitation method in children with adolescent idiopathic scoliosis: A randomized clinical trial

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Abstract

This study aimed to investigate the effect of Pilates-based exercise training applied with hybrid telerehabilitation on Cobb angle, respiratory function, respiratory muscle strength, and functional capacity in patients with adolescent idiopathic scoliosis (AIS). This is an evaluator-blinded, randomized, controlled trial. For the study, 32 patients were randomly allocated into two groups: a hybrid telerehabilitation group (training group), provided with modified Pilates-based exercises with synchronous sessions; and a home-based group (control group), doing the same exercises in their home. The Pilates-based exercise program consists of stretching and strengthening exercises combined with postural corrections and breathing exercises modified according to the curve type and localization of the patients, done every day of the week for 12 weeks. Analyses were made based on the comparison between the angle of trunk rotation, Cobb angle, spirometry, maximal inspiratory (MIP) and expiratory pressures (MEP), and incremental shuttle walk tests done at the beginning and end of the study. The training group showed statistically significant improvements in Cobb angle, PEF%, MIP, and MEP values compared with the control group ($p < 0.05$).

Conclusion: Pilates-based exercises applied with the hybrid telerehabilitation method can improve Cobb angle and respiratory muscle strength in patients with AIS. The hybrid telerehabilitation method can be used as an alternative to home-based programs, especially in locations and times where there may be limited access to supervised training. Also, the nature of the disease that requires long-term follow-up is another factor where hybrid telerehabilitation may be an advantage.

Trial registration: ClinicalTrials.gov ID: NCT05761236.

What is Known:
- *Exercise training is one of the main approaches to treating scoliosis.*

What is New:
- *Application of exercises via telerehabilitation method may contribute more to the improvement of scoliosis-related parameters than home-based programs.*
- *Telerehabilitation may be a preferable alternative exercise method in scoliosis, considering the advantages of accessibility and long-term follow-up.*

Keywords Adolescent idiopathic scoliosis · Telerehabilitation · Pilates exercises · Cobb angle · Respiratory parameters

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Abbreviations

AIS	Adolescent idiopathic scoliosis
ATR	Angle of trunk rotation
FVC	Forced vital capacity
FEV_1	Forced expiratory volume in 1 s
FEV_1/FVC	Tiffeneau ratio
PEF	Peak expiratory flow
MIP	Maximal inspiratory pressure
MEP	Maximal expiratory pressure
ISWT	Incremental shuttle walking test

Introduction

Adolescent idiopathic scoliosis (AIS), the most common type of idiopathic scoliosis, occurs in children from the age of 10 until skeletal maturation is complete, without any known cause [1]. Theories for the multifactorial pathogenesis of AIS include genetic, histological, biomechanical, neurological, hormonal, and environmental factors. Biomechanical problems arising from the structure of the deformity, such as displacement of the spine and rotation of the rib cage, can lead to restrictive breathing patterns [2–4]. Therefore, changes in respiratory functions, respiratory muscle strength, and functional capacity can be seen in patients with AIS [5, 6].

Treatment alternatives for AIS include surgical and conservative approaches depending on the severity of the deformity. Conservative treatment options consist of observation, exercise programs, and orthotics. Three principles required for exercise approaches to be effective in AIS are to organize the exercises in a way to correct the deformity by considering the three-dimensional structure of scoliosis, to stabilize the posture by bringing the body segments to the midline, and to maintain this corrected posture in daily life [7]. Although there are limited studies in the literature investigating the effects of Pilates exercises on scoliosis, it is thought to have a positive effect.

All of the scoliosis and exercise training studies in the literature consist of clinical-based supervised or home-based programs. There is no study in which exercise training was given to patients with AIS using the telerehabilitation method. Telerehabilitation is an innovative rehabilitation method that enables healthcare professionals to conduct their sessions remotely through telecommunication technologies. Telerehabilitation methods may be suitable for scoliosis patients because of high accessibility and participation rates, easier behavioral changes in life style, and providing patients to continue rehabilitation in their own home environment for a longer period of time [8]. Hybrid type programs, on the other hand, are a special form of telerehabilitation that allows patients to continue their sessions at home after clinical-based rehabilitation programs. Considering the age range of AIS, this two-phase method may be more applicable for patients to comprehend the steps of exercise training and postural corrections.

In the light of this information, this study aimed to investigate the effect of Pilates-based exercise training applied with a hybrid telerehabilitation method on Cobb angle, respiratory function, respiratory muscle strength, and functional capacity in patients with AIS.

Materials and methods

Study design

This prospective, randomized, controlled, evaluator-blinded trial was approved by the clinical research ethics committee of Bezmialem Vakif University (050.05.04-10/214) and registered to ClinicalTrials.gov with ID-number NCT05761236. This study was conducted in the Physiotherapy and Rehabilitation Department of the Faculty of Health Sciences at Bezmialem Vakif University between August 2021 and November 2022 in accordance with the Declaration of Helsinki. All patients and their parents were informed about the purpose of the study and how the study was going to be carried out beforehand. Written informed consent was obtained from all of the participants' parents.

Participants were selected based on the following inclusion criteria: having a diagnosis of AIS, being between the ages of 10 and 18, having a Cobb angle between 25 and 50°, having electronic devices that will provide internet connection and video-conference at the patients' home. The exclusion criteria were as follows: undergoing a surgical operation in the last 3 months; having an orthopedic, neurological, or mental disease that prevents from exercising; doing regular exercises at least 3 days a week with an exercise program.

Among the patients who applied to the Scoliosis Outpatient Clinics of Bezmialem Vakıf University Hospital, 32 patients who met the inclusion criteria of our study were referred to our department after medical doctor evaluation. The patients participating in our study were randomized into two groups as the training and control groups after their initial evaluation.

Respiratory function, respiratory muscle strength, and functional capacity were evaluated at the beginning and end of the study. The evaluations were made by another physiotherapist who was blinded to the study.

Measurement

Cobb angle and Risser classification were evaluated at the beginning and end of the study by the same orthopedist who was blind to the group allocation in the study.

The angle of trunk rotation (ATR) was measured with a Bunnell scoliometer [9].

"COSMED Pony-FX" (COSMED-Italy) spirometry device was used to evaluate pulmonary functions, and measurements were performed in accordance with ATS/ERS criteria [10]. The best of three tests consistent with each other was selected and recorded. Forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), Tiffeneau ratio (FEV_1/FVC), and peak expiratory flow (PEF) values were measured and recorded as percentages of expected values with the pulmonary function test [11].

Respiratory muscle strength was measured in accordance with ATS/ERS criteria using an electronic and portable respiratory pressure measuring device (MicroRPM, Micro Medical, UK). For each evaluation, the measurement was repeated three times and the highest value was recorded [12].

Exercise capacity was assessed by the incremental shuttle walking test (ISWT) according to methods described by Singh et al. [13]. The distance walked by the patients was recorded in meters.

Intervention

Exercise sessions were planned as 10-min warm-up-cool-down and 40-min scoliosis-specific, Pilates-based exercises for approximately 1 h. The total number of exercises was 12 for one session. The exercises were planned to be done every day of the week for 12 weeks, getting progressively more difficult over the weeks. The total number of repetitions and the number of sets were the same but bilateral or unilateral directions of application, the number of repetitions for the right and left sides, and the extremities used were modified for each patient according to the location of the major curve and the type of the curve. The participants were asked to maintain the postural corrections they were taught throughout all the exercises.

Exercises for flexibility in the warm-up and cool-down phases were performed.

The strengthening exercises in the exercise phase were determined by considering the curve type and by arranging the number of repetitions for the right and left side in the direction of the target muscles, with a total of 12 repetitions with 5-s contractions.

The patients were asked to breathe towards the weak breathing zones (towards the concave side of the major curve) during the exercises (Supplement I and II).

All patients received Pilates-based exercise training with supervision once a week for the first 2 weeks. Afterwards, the control group applied this exercise program at home for 1 h a day, every day for 10 weeks. Weekly exercise lists were sent to the patients in the form of electronic booklets. The training group switched to hybrid type telerehabilitation and continued their exercise sessions with a physiotherapist 3 days a week via synchronous video conferences, and on their own on the remaining days of the week. The exercise continuity of all patients was checked with exercise diaries.

Statistical analysis and sample size

Statistical analysis was conducted using IBM SPSS v.26 (SPSS Inc.). The normality of the distribution of data was analyzed using the Shapiro–Wilk Test. Categorical variables were compared between groups using the χ^2 test. Independent Samples *T*-test or Mann–Whitney *U* test was used for between-group comparisons depending on the distribution properties of the data. Cohen's d efect sizes were calculated for between-group differences. A repeated measure analysis of variance (ANOVA) was used for the analysis of intra-group changes. A mixed ANOVA (repeated-measures analysis of variance with between-subjects factor) was used to analyze whether the effects of interventions differed between the groups. The results were considered significant with *p* values < 0.05. Complementarily, the effect size was calculated by partial eta-squared (ηp^2) with small, medium, and large effect sizes classified as 0.01, 0.06, and 0.14, respectively [14].

The G*Power 3.1 (Universitaet Dusseldorf, Germany) software was used for the sample size calculation [15]. Based on the results of a study in the literature, we estimated a sample size of 13 children for each group [16]. The sample size calculation was made at 80% power and a two-tailed α level of 0.05 with the 1.148 effect size based on the comparison of the changes in the MEP value. The number of participants was calculated with a 20% increase in sample size in case of any drop-outs.

Results

Fifty children and adolescents with AIS were assessed for eligibility. Thirty-two patients who met the inclusion criteria were included in this study and randomized. One patient from the control group dropped out due to non-compliance with the exercise program. Thirty-one patients with AIS completed the study (Fig. 1). No adverse events or significant harm were recorded throughout the intervention period.

The comparison of the demographic and clinical characteristics of the groups is given in Table 1.

A comparison of baseline values of ATR, Cobb angle, pulmonary function, respiratory muscle strength, and functional capacity of both groups is given in Table 2.

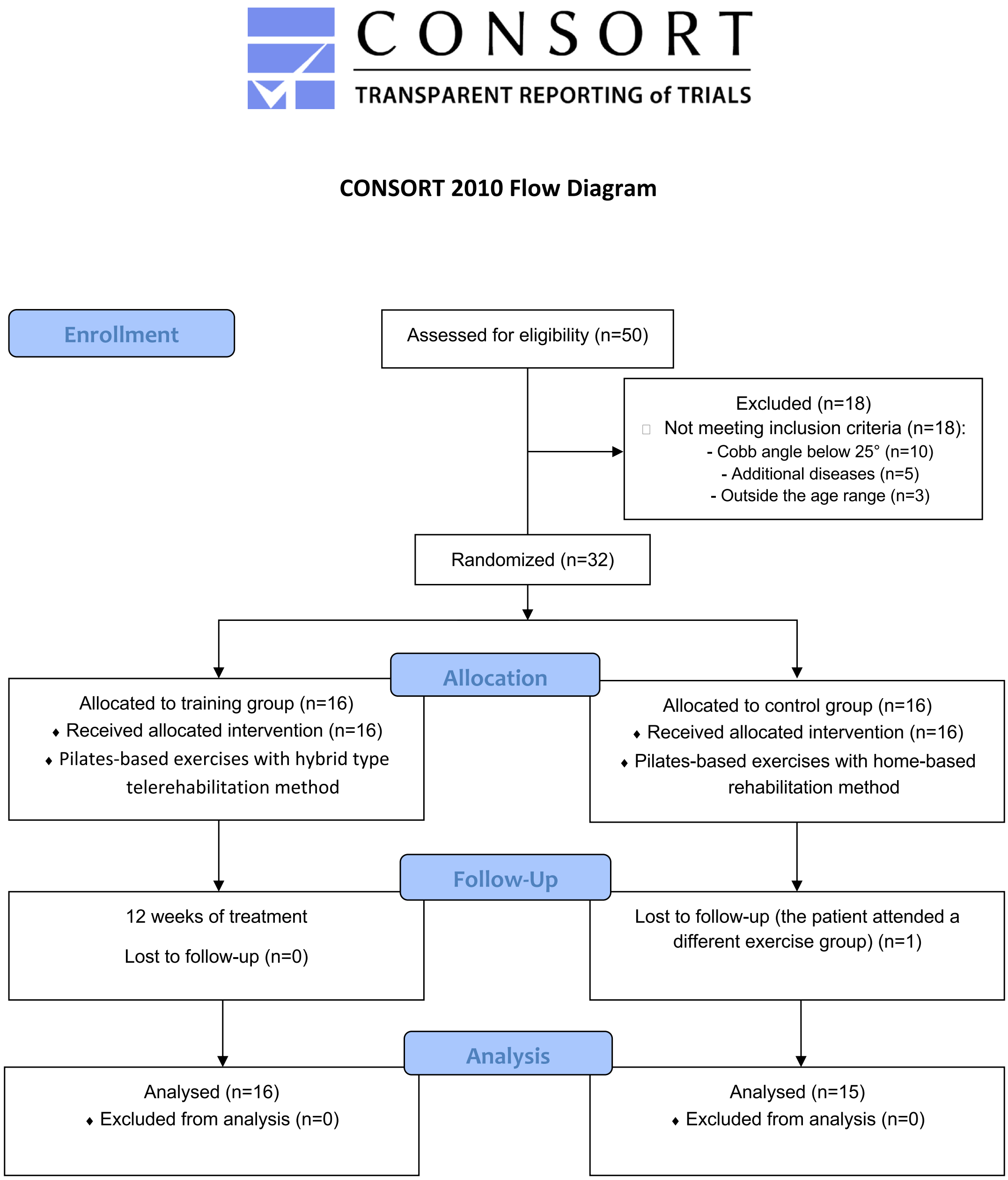

Fig. 1 The flowchart of participant recruitment in this study

Intergroup and intragroup differences are given in Table 3. The thoracic and lumbar ATR and ISWT distance were significantly improved in both control and training groups without any significant intergroup differences. There was a significant improvement in FEV_1% only in the training group, but this improvement was not statistically significant between the groups.

There was a significant interaction between time and group for Cobb angle, PEF, maximal inspiratory pressure (MIP), and maximal expiratory pressure (MEP) with a large effect size which indicates that all these parameters increased more significantly in the training group compared to the control group ($p=0.011$, $\eta p^2=0.205$; $p=0.026$, $\eta p^2=0.159$; $p=0.011$, $\eta p^2=0.203$; $p=0.034$, $\eta p^2=0.146$, respectively).

A comparison of the intra-group changes in Cobb angle, angle of trunk rotation, pulmonary function, respiratory muscle strength, and functional capacity between control and training groups is given in Table 4. The magnitude of improvement in Cobb angle, PEF, and MEP, having a medium effect size, while MIP, having a large effect size, was significantly greater in the training group compared to the control group.

Table 1 Demographic and clinical characteristics of the control and training groups

	Control group ($n=15$)	Training group ($n=16$)	p
Gender, (female/male)	15/0	15/1	0.325
Body mass index (kg/m^2), mean (SD)	19.91 (3.41)	17.72 (2.26)	0.047
Curve type, *n* (%)			
Thoracic	9 (60%)	8 (50%)	
Lumbar	6 (30%)	6 (37.5%)	0.240
Thoracic-lumbar	0 (0%)	2 (12.5%)	
With brace, *n* (%)	7 (46.6%)	8 (50%)	0.853
Dominant hand, (right/left)	10/5	16/0	0.027
Risser sign, mean (SD)	2.40 (1.63)	2.75 (1.57)	
0	3	3	
1	1	0	
2	4	2	0.548
3	2	5	
4	4	5	
5	1	1	

Data are presented as mean (SD), *n* and *n* (%)

Discussion

In this prospective, randomized, controlled, and single-blinded study examining the effects of Pilates-based modified exercise programs applied with different methods on Cobb angle, respiratory function, respiratory muscle strength, and functional capacity in patients with AIS, we found that the program applied with synchronous telerehabilitation sessions was more effective in improving Cobb angle, PEF, MIP, and MEP. Additionally, thoracic-lumbar ATR and functional capacity improved significantly in both groups.

In the literature, there are many studies examining the effect of different exercise training methods on Cobb angle in patients with AIS. In these studies, a significant decrease was found in Cobb angle values with exercise training [17–19]. In a study in which two different breathing techniques and Pilates exercises were applied together in patients with

Table 2 Comparison of the baseline values in the angle of trunk rotation, Cobb angle, pulmonary function, respiratory muscle strength and functional capacity between control and training groups

	Control group ($n=15$) Baseline	Training group ($n=16$) Baseline	p	95% CI
Angle of trunk rotation				
Thoracic (°)	5.86 ± 4.73	7.12 ± 5.52	0.501	− 5.03–2.51
Lumbar (°)	6.60 ± 3.33	5.00 ± 4.13	0.244	− 1.15–4.35
Cobb angle (°)	31.60 ± 6.08	37.50 ± 7.37	0.021	− 10.85–0.94
Pulmonary function				
FVC %pred	102.06 ± 11.22	92.62 ± 11.59	0.029	1.05–17.82
FEV_1 %pred	100.86 ± 11.78	88.50 ± 11.92	0.007	3.65–21.08
FEV_1/FVC (%)	109.20 ± 6.12	101.93 ± 8.41	0.010	1.86–12.65
PEF %pred	108.20 ± 15.77	87.93 ± 13.29	0.001	9.48–31.03
Respiratory muscle strength				
MIP (cmH_2O)	62.40 ± 12.03	51.06 ± 13.85	0.021	1.81–20.85
MEP (cmH_2O)	73.20 ± 16.55	67.75 ± 13.05	0.320	− 5.59–16.49
Functional capacity				
ISWT; distance (m)	392.66 ± 69.02	483.68 ± 106.20	0.009	− 156.76 to − 25.27

Data are presented as mean ± SD

FVC forced vital capacity, *FEV1* forced expiratory volume in 1 s, *PEF* peak expiratory flow, *MIP* maximal inspiratory pressure, *MEP* maximal expiratory pressure, *ISWT* incremental shuttle walk test

Table 3 Effects of pilates-based exercise training applied by hybrid type telerehabilitation method on the angle of trunk rotation, Cobb angle, pulmonary function, respiratory muscle strength, and functional capacity

	Control group ($n=15$)			Training group ($n=16$)			Intergroup differences**		
	Baseline	Post-training	Intragroup differences*	Baseline	Post-training	Intragroup differences*	Time	Group	Time × group
Cobb angle (°)	31.60 ± 6.08	30.57 ± 6.64	$F=1.070$ $p=0.318$ $\eta p^2=0.071$	37.50 ± 7.37	32.43 ± 7.06	$F=21.894$ $p<0.001$ $\eta p^2=0.593$	$F=17.050$ $p<0.001$ $\eta p^2=0.370$	$F=2.758$ $p=0.108$ $\eta p^2=0.087$	$F=7.478$ $p=0.011$ $\eta p^2=0.205$
Angle of trunk rotation									
Thoracic (°)	5.86 ± 4.73	4.92 ± 4.07	$F=8.704$ $p=0.011$ $\eta p^2=0.383$	7.12 ± 5.52	6.40 ± 4.95	$F=5.640$ $p=0.031$ $\eta p^2=0.273$	$F=17.261$ $p=0.001$ $\eta p^2=0.330$	$F=0.622$ $p=0.437$ $\eta p^2=0.021$	$F=0.250$ $p=0.621$ $\eta p^2=0.009$
Lumbar (°)	6.60 ± 3.33	5.78 ± 3.18	$F=8.649$ $p=0.011$ $\eta p^2=0.382$	5.00 ± 4.13	4.37 ± 3.75	$F=4.747$ $p=0.046$ $\eta p^2=0.240$	$F=12.973$ $p=0.001$ $\eta p^2=0.309$	$F=1.361$ $p=0.253$ $\eta p^2=0.045$	$F=0.224$ $p=0.639$ $\eta p^2=0.008$
Pulmonary function									
FVC %pred.	102.06 ± 11.22	104.21 ± 10.82	$F=1.511$ $p=0.239$ $\eta p^2=0.097$	92.62 ± 11.59	94.50 ± 14.13	$F=2.412$ $p=0.141$ $\eta p^2=0.139$	$F=3.666$ $p=0.065$ $\eta p^2=0.11\ 2$	$F=5.199$ $p=0.030$ $\eta p^2=0.152$	$F=0.017$ $p=0.898$ $\eta p^2=0.001$
FEV_1%pred.	100.86 ± 11.78	101.85 ± 11.74	$F=0.769$ $p=0.395$ $\eta p^2=0.052$	88.50 ± 11.92	91.93 ± 12.46	$F=10.352$ $p=0.006$ $\eta p^2=0.408$	$F=8.123$ $p=0.008$ $\eta p^2=0.219$	$F=6.910$ $p=0.014$ $\eta p^2=0.192$	$F=2.481$ $p=0.126$ $\eta p^2=0.079$
FEV_1/FVC (%)	109.20 ± 6.12	107.92 ± 6.33	$F=2.282$ $p=0.153$ $\eta p^2=0.140$	101.93 ± 8.41	104.12 ± 5.18	$F=1.827$ $p=0.196$ $\eta p^2=0.109$	$F=0.242$ $p=0.626$ $\eta p^2=0.008$	$F=6.352$ $p=0.017$ $\eta p^2=0.180$	$F=3.456$ $p=0.073$ $\eta p^2=0.106$
PEF %pred.	108.20 ± 15.77	112.28 ± 12.96	$F=2.438$ $p=0.141$ $\eta p^2=0.148$	87.93 ± 13.29	101.81 ± 13.09	$F=18.632$ $p=0.001$ $\eta p^2=0.554$	$F=18.486$ $p<0.001$ $\eta p^2=0.389$	$F=11.654$ $p=0.002$ $\eta p^2=0.287$	$F=5.492$ $p=0.026$ $\eta p^2=0.159$
Respiratory muscle strength									
MIP (cmH_2O)	62.40 ± 12.03	76.34 ± 21.28	$F=16.936$ $p=0.001$ $\eta p^2=0.547$	51.06 ± 13.85	76.50 ± 6.37	$F=97.429$ $p<0.001$ $\eta p^2=0.867$	$F=86.934$ $p<0.001$ $\eta p^2=0.750$	$F=1.424$ $p=0.242$ $\eta p^2=0.047$	$F=7.399$ $p=0.011$ $\eta p^2=0.203$
MEP (cmH_2O)	73.20 ± 16.55	91.14 ± 20.32	$F=21.024$ $p<0.001$ $\eta p^2=0.600$	67.75 ± 13.05	96.43 ± 8.37	$F=98.195$ $p<0.001$ $\eta p^2=0.867$	$F=93.392$ $p<0.001$ $\eta p^2=0.763$	$F=0.000$ $p=0.987$ $\eta p^2=0.000$	$F=4.959$ $p=0.034$ $\eta p^2=0.146$
Functional capacity									
ISWT; distance (m)	392.66 ± 69.02	420.00 ± 49.71	$F=3.332$ $p=0.049$ $\eta p^2=0.192$	483.68 ± 106.20	517.50 ± 115.78	$F=5.236$ $p=0.037$ $\eta p^2=0.259$	$F=8.436$ $p=0.007$ $\eta p^2=0.225$	$F=9.458$ $p=0.005$ $\eta p^2=0.246$	$F=0.095$ $p=0.760$ $\eta p^2=0.003$

Data are presented as mean ± SD

FVC forced vital capacity, *FEV1,* forced expiratory volume in 1 s, *PEF* peak expiratory flow, *MIP* maximal inspiratory pressure, *MEP* maximal expiratory pressure, *ISWT* incremental shuttle walk test

*Repeated-measures ANOVA

**Mixed ANOVA

scoliosis, it was reported that the Cobb angle decreased significantly for both groups [20]. Unlike the studies mentioned above, there are also studies in the literature in which 8 weeks of clinical Pilates training was given to patients with AIS, and no significant improvement in Cobb angles was reported [21]. When the initial Cobb angles of the patients with AIS in our study were examined, it was seen that our patients had moderate and moderate-severe scoliosis. We think that the reason for the further improvement in the Cobb angles of the patients in our telerehabilitation group was the fact that the program consisting of postural corrections, breathing patterns, and modified exercises were performed in a more controlled manner by the patients under the supervision of the physiotherapist during the synchronous sessions.

Respiratory functions may decrease in patients with AIS due to the angle of the curve, loss of normal kyphosis in the thoracic spine, and rotation of the vertebrae [22]. When the literature is examined, it is seen that the pulmonary function test parameters of children with AIS are lower than healthy children in the same age range [6, 23–25]. Lung function abnormalities become evident when the Cobb angle is above 50–60° in scoliosis [26]. In parallel with the literature, the pulmonary function parameters of the patients included in our study were within normal limits (97% of all AIS).

Although there is no study in the literature showing the effect of Pilates exercises or any exercise program applied with the telerehabilitation method on pulmonary function test parameters in patients with AIS, there are limited

Table 4 Comparison of the intra-group changes in Cobb angle, angle of trunk rotation, pulmonary function, respiratory muscle strength, and functional capacity between control and training groups

	Control group ($n = 15$) In-group change (Δ)	Training group ($n = 16$) In-group change (Δ)	p	Effect size Cohen's d
Cobb angle (°)	− 1.02 ± 3.85	− 5.06 ± 4.32	0.011	0.59
Angle of trunk rotation				
Thoracic (°)	− 0.93 ± 1.23	− 0.71 ± 1.21	0.621	− 0.08
Lumbar (°)	− 0.81 ± 1.07	− 0.62 ± 1.14	0.639	− 0.04
Pulmonary function				
FVC %pred	2.14 ± 6.76	1.87 ± 4.82	0.898	− 0.05
FEV_1 %pred	0.99 ± 4.37	3.43 ± 4.27	0.126	− 0.22
FEV_1/FVC (%)	− 1.27 ± 3.25	2.18 ± 6.47	0.073	− 0.45
PEF %pred	4.08 ± 10.13	13.87 ± 12.85	0.026	− 0.65
Respiratory muscle strength				
MIP (cmH_2O)	13.94 ± 13.12	25.43 ± 8.69	0.011	− 0.86
MEP (cmH_2O)	17.94 ± 15.15	28.50 ± 5.58	0.034	− 0.70
Functional capacity				
ISWT; distance (m)	27.33 ± 57.99	33.81 ± 59.10	0.760	− 0.07

Data are presented as mean ± SD

FVC forced vital capacity, *FEV1* forced expiratory volume in 1 s, *PEF* peak expiratory flow, *MIP* maximal inspiratory pressure, *MEP* maximal expiratory pressure, *ISWT* incremental shuttle walk test

studies showing the effects of different exercise protocols. Amaricai et al. reported that after 12-week supervised exercise training (stretching, strengthening, rotational breathing, core exercises), although there were significant improvements in respiratory parameters, patients did not reach the values of the healthy control group [27].

Studies investigating the effect of supervised core exercises in patients with AIS (although there are differences in their duration and methods) have reported significant increases in FVC, FEV_1, FEV_1/FVC, MIP, and MEP in the training group [16, 28].

Consistent with the literature, significant increases were observed in the FEV_1% and PEF% in the training group of our study. However, only the PEF% value created a statistically significant difference between the groups. PEF is the maximum rate of flow in forced expiration starting from full inspiration. Maximal airflow occurs during the effort-dependent portion of the maneuver; thus, PEF not only reflects airway caliber but also muscle strength and voluntary effort [29]. Considering that Pilates exercises strengthen the muscles in the core region, which are among the primary inspiratory muscles, the improvement in the two groups we have achieved in PEF is not surprising. The greater improvement in PEF value in our training group may be due to the fact that the auditory and visual feedback given by the physiotherapist during the telerehabilitation-supervised sessions allowed the patients to more accurately perform the breathing exercises in postural corrections and modified exercises.

Biomechanical problems in the rib cage, which forms the attachment surface for respiratory muscles, and common muscle dysfunction seen in patients with AIS may cause changes in the contraction-relaxation abilities and configurations of the respiratory muscles. Thus, the power generation potential of these muscles decreases and the respiratory workload increases [30, 31]. Due to these changes, it is thought that MIP and MEP in patients with AIS are lower than healthy controls in the same age range. In line with the literature, respiratory muscle strength values of patients with AIS in our study were low compared to the predictive values stated for their healthy peers [6, 24, 32]. There is no study in the literature showing the effect of Pilates exercises on respiratory muscle strength in patients with AIS. Studies examining the effectiveness of core stabilization exercises on respiratory muscle strength in patients with AIS have shown that these exercise training programs can significantly increase MIP and MEP [16, 28]. It has been reported that aerobic exercise increases respiratory muscle strength in children with AIS with a Cobb angle greater than 45° [33].

Similar to the literature, statistically significant increases were observed in post-treatment MIP and MEP in both groups in our study. These increases were statistically significantly higher in our training group.

The biomechanical function of the core muscles is very important in Pilates training, because the core muscles stabilize the spine by providing cooperation between the deep and superficial muscles, are effective in controlling the movements of the person to maintain the neutral position of the spine, and control the intra abdominal pressure which plays an important role in breathing and stabilizing the trunk. We think that the improvement in MIP and MEP in both of our groups may be related to the activation of the diaphragm and transversus abdominis muscles, the increased intra-abdominal pressure, and the decreased intrathoracic pressure and the increased ventilation by contractioning in the abdominal wall. Also, Pilates training can stimulate the plasticity and symmetrical development of the trunk. This may have increased the muscle strength of the respiratory muscles and the muscles around the spine. Maintaining the postural corrections and respiratory components simultaneously with exercise can be complex for patients at times. The supervised nature of the telerehabilitation sessions may have facilitated the control of these components and may have caused further improvement in MIP and MEP in our training group.

There are many different views on the causes of changes in functional capacity in patients with AIS. One of these views states that functional capacity may be reduced due to cardiovascular and ventilatory limitations, general muscle dysfunction including respiratory muscles, or biomechanical deformities [6].

When the literature was examined, it was found that the functional capacities of patients with AIS were lower than those of healthy children [23, 24, 34]. In our study, the walking distance of both groups was similar to the values of patients with AIS in the literature.

There were no studies in the literature showing the effect of Pilates exercises on functional capacity in patients with AIS. In a study evaluating the effect of core stabilization-based exercises on functional capacity in AIS patients using 6MWT, it was reported that this exercise training significantly improved functional capacity [27]. In their study with patients with AIS, Yildirim et al., who gave traditional scoliosis exercises to the control group and additional core stabilization exercises to the training group, reported that the distance walked increased in both groups, but the difference between the groups was not significant [16]. Similar to the literature, in our study, statistically significant increases were observed in ISWT walking distances for both groups compared to pre-treatment values. The post-treatment ISWT walking distance increases were 33.81 ± 57.99 and 27.33 ± 57.99 m for the training and control groups, respectively. When the increases in ISWT walking distance values were compared between the groups, the difference was not statistically significant, similar to the study of Yildirim et al., considering that exercise training was applied to the control groups in both studies, it is expected for the results observed after the treatment to be similar [16].

Based on the relationship between low exercise capacity and general muscle dysfunction in patients with AIS, improvements in inspiratory muscles and upper-lower limb muscle strengths may increase the functional capacity [6, 35]. These are the main muscles that Pilates-based exercise training focuses on, and since they are skeletal muscles, they respond to appropriate loading with muscle strength increase.

A potential limitation of our study is that the exercises applied with telerehabilitation include visual and auditory stimuli, but do not allow tactile stimuli due to their structure. Although the brace usage rates did not make a statistically significant difference between the groups to which the patients were randomly distributed, the difference in the percentages between the groups may be another potential limitation of our study.

Conclusions

In conclusion, Pilates-based exercises applied with the hybrid telerehabilitation method significantly improve Cobb angle, PEF%, and respiratory muscle strength in AIS.

We would like to inform you that home-based Pilates exercises can be preferred as an effective method for the conservative treatment of patients with AIS, and that it can also be very useful in terms of the additional benefits of the Pilates exercise program applied with hybrid telerehabilitation. We think that the hybrid telerehabilitation method can be used as an alternative to home-based programs, especially in locations and times where there may be limited access to supervised training. In addition, the nature of the disease that requires long-term follow-up is another factor where hybrid telerehabilitation may be an advantage.

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Authors' contributions ASMD: data curation, formal analysis, investigation, methodology, resources, writing—original draft. SO: methodology, project administration, investigation, resources, supervision, writing—original draft, writing—review and editing. HU: data curation, formal analysis. NME: investigation, methodology, resources, supervision, writing—review and editing.

Declarations

Competing interests The authors declare no competing interests.

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