Impact of Schroth three-dimensional *vs.* proprioceptive neuromuscular facilitation techniques in adolescent idiopathic scoliosis: a randomized controlled study

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Abstract. – OBJECTIVE: The aim of the study was to investigate the effect of proprioceptive neuromuscular facilitation (PNF) and compare its effect to the Schroth exercises on scoliosis angle, static plantar pressure distribution, and functional capacity in adolescent idiopathic scoliosis.

PATIENTS AND METHODS: Thirty-four girls (aged 14-16 years) with thoracolumbar curves were randomly distributed into two study groups of equal numbers. The Schroth group underwent Schroth exercises, whereas the PNF group underwent treatment using proprioceptive neuromuscular facilitation. Patients in both groups received treatment for one hour, three times per week for six successive months. Measurements of Cobb's angle, angle trunk rotation, total static plantar pressure on both lower limbs, and functional capacity using the six-minute walk test were performed just before and after six months of treatment.

RESULTS: A significant decrease in Cobb's angle and right total static plantar pressure with a significant increase in left total static plantar pressure post-treatment was noted in both groups, with a higher effect in the Schroth group. A significant increase was recorded in the six-minute walk test with a decrease in angle trunk rotation in the Schroth group, while no significant changes were recorded in the PNF group.

CONCLUSIONS: Based on the results obtained in this study, this program of PNF patterns did not show a significant improvement in angle trunk rotation, which is a critical aspect in correction of the curve in comparison to the Schroth exercises. These proprioceptive neuromuscular facilitation patterns are not recommended for the correction of adolescent idiopathic scoliosis.

Key Words:
Functional capacity, Plantar pressure, Proprioceptive neuromuscular facilitation, Schroth, Scoliosis.

Abbreviations

ADLS: Daily living activities; AIS: Adolescent idiopathic scoliosis; ART: Angle trunk rotation; CNS: Central nervous system; COG: Centre of gravity; PNF: Proprioceptive neuromuscular facilitation; PSSE: Physiotherapeutic scoliosis-specific exercises; ROM: Range of motion; RAB: Rotational angular breathing; 3D: Three dimensional.

Introduction

Adolescent idiopathic scoliosis (AIS) is the most common spinal structural deformity in adolescence[1]. AIS is a progressive disease[2] with a higher rate and severity in girls[3]. It is a three-dimensional (3D) deformity with a Cobb's angle of more than 10°. Mild scoliosis is considered when the Cobb's angle is up to 25°. Angles from 25° to 45° are considered moderate scoliosis, while angles greater than 45° are considered severe scoliosis. If the spine curvature is greater than 30° in late childhood, the potential risks will greatly increase in adulthood. These risks include pain, thoracic and shoulder girdle malformations, lower quality of life, and respiratory disorders[4]. Scoliosis causes changes in the erector spinae muscle characteristics, imbalance in the trunk and pelvis, decrease in spinal flexibility, and effects on the patients' self-image, causing an irreversible psychological impact[5].

The position of the weight distribution depends on the shape of the scoliosis and the Cobb's angle. In AIS with a C-shaped lumbar or thoracolumbar curve, the centre of gravity (COG) is shifted toward the convex side which leads to a change in plantar pressure distribution. The body pressure distribution was tilted on the left

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side more than on the right side in left scoliosis. In contrast, body pressure increased on the right side in right scoliosis. The difference in foot pressure distribution increased with an increase in the degree of scoliosis[6]. Reduced functional capacity[7] and impaired exercise tolerance are early manifestations of mild scoliosis[8]. Lifting, sitting, and standing for long periods of time and walking for long distances are demanding physical tasks for patients with scoliosis[9]. As soon as the diagnosis is recognised, appropriate treatment should be implemented to correct the deformity and prevent long-term effects[10].

The treatment of AIS depends on several factors, including patient age, Cobb's angle, and Risser scale[11]. Scoliosis treatment can be conservative or surgical. Conservative treatment includes physiotherapy and/or bracing. Physiotherapy is indicated for mild curves, and bracing is used for moderate curves, at a growth stage Risser 0-3[12]. The goals of the exercises are to retard curve progression, reduce pain, increase neuromotor control and stability of the spine, prevent or treat secondary functional impairments, and delay or avoid the need for bracing. Exercises include strengthening, mobilisation, breathing exercises, Pilates, tai chi, and yoga[4].

Physiotherapeutic scoliosis-specific exercises (PSSE) are used to treat scoliosis[13,14]. PSSE is a curve-specific exercise program that varies according to an individual's scoliosis curve characteristics. PSSE had a superior effect on general exercises, such as yoga, Pilates, and routine physiotherapy[14]. The Schroth exercises are the PSSE method used to treat AIS in young patients. Schroth exercises are effective in 10° to 45° curves, leading to an increase in self-esteem[15]. In a systematic review, Schroth exercises caused a decrease in the Cobb's angle, slowing the rate of curve progression and improving back muscle strength and respiratory functions[16]. Correction of the curve is achieved by combining strengthening, stretching, and breathing exercises in reverse directions of all abnormal curvatures, based on an individual's spinal deformity[14]. It uses sensory stimulations and mirror control to correct scoliosis and breathing pattern[17]. Patients learn to change themselves as far as possible from a position of solely passive support by the spinal ligaments, which is thought to promote curve progression through the active trunk muscle force to maintain the correct posture during the activities of daily living (ADL_S). This correction is maintained by rotational angular breathing (RAB)[18].

The proprioceptive neuromuscular facilitation (PNF) method involves movement patterns and techniques for improving the range of motion. These patterns allow selective working on particular parts of the body, including the spine[19]. This method does not belong to the PSSE and is less frequently used for scoliosis treatment. It is based on research projects which have demonstrated that spinal curvature is also associated with disturbances in the central nervous system (CNS). At the developmental stage, these disorders cause deviations in the CNS, leading to the asymmetry of motor activity and, consequently, incorrect position of the spine. The progressive deformation of the spine leads to an increased asymmetry of body functions. This elevated asymmetry is understood by the nervous system as a norm, which causes children to cease to sense the correct body position[20].

Previous studies[11, 21-23] have demonstrated the significant effects of Schroth 3D exercises on improving AIS, but there is no evidence for PNF; however, only a limited number of studies have been conducted[24-26]. Therefore, this study aimed to investigate the effect of PNF and compare its effect to Schroth exercises on scoliosis angle, static plantar pressure distribution, and functional capacity in AIS.

Patients and Methods

Study Design

This was an interventional, randomised, parallel group study for six successive months. The study was conducted at the outpatient clinic of Al-Qassim University, Saudi Arabia. The registration trial was UMIN000042363.

This study was approved by the Ethics Committee of Al-Qassim University and in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Before the patients were allowed to participate, their parents signed a consent form. The intent of the study and its procedures were explained to all parents.

Sample Size

G*POWER statistical software was used before the study (version 3.1.9.2; Franz Faul, Universitat Kiel, Germany) to calculate the sample size using $\alpha = 0.05$, $\beta = 0.2$, and a medium effect. The appropriate sample size was $n = 34$, which provided a power of 0.8.

Patients

Thirty-four female students with right single thoracolumbar AIS, ranging in age from 14 to 16 years, were enrolled in this study. The eligibility criteria included: angle of scoliosis < 25°, Risser sign of II-V, not participating in other treatments during the study, and not using braces or muscle relaxants.

The exclusion criteria included scoliosis due to congenital, neuromuscular, or syndromic aetiology, true leg length discrepancy, cardiac anomalies, kyphosis, asthma, and other pulmonary diseases.

Randomisation, Allocation, and Blinding

A research coordinator screened 37 patients for eligibility. Three patients were excluded because they did not meet the eligibility criteria. The total number of participants was 34. Following the study inclusion, the eligible patients were randomly assigned to one of two groups (Schroth or PNF) with a 1:1 allocation ratio of equal numbers n = 17, according to a randomisation schema generated by the computer which provided blocks of randomly varied sizes. Once randomisation was performed, group allocation was apparent exclusively via the Clean Web to the physiotherapist who was non-blinded and not involved in the study. The physiotherapist verbally informed the patients. Before the start of the study, the allocation list was performed by an off-site statistician who was not involved in the study.

After allocation, no children dropped out of the study. The study diagram based on the CONSORT guidelines[27] is shown in Figure 1.

Outcome Measures

All measurements were performed for all patients in both groups by the same blinded researcher under the same conditions immediately before and after six successive months of treatment. The researcher was unaware of the group assignments. Cobb's angle and angle trunk rotation (ATR) measurements were performed as a primary outcome measure, while static plantar pressure distribution and functional capacity were considered as secondary outcome measures.

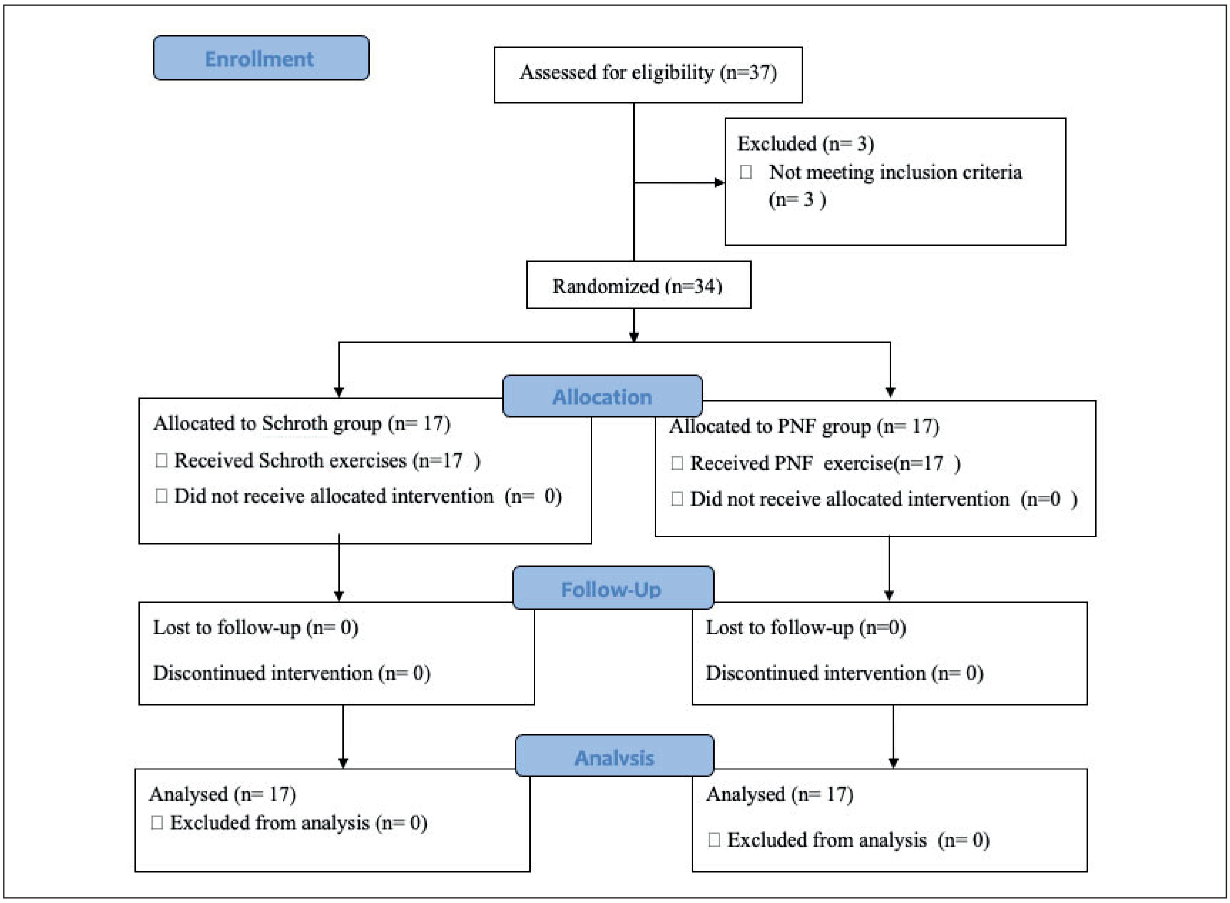

Figure 1. Flow diagram of the study.

Preliminary evaluation of body weight (kg) and height (cm) using the scale (health scale 70, China) was performed for all eligible patients.

Cobb's Angle

To determine the Risser sign grading and Cobb's angle, an anterior-posterior full spine and pelvis plain X-ray was performed (with an average error of ±3.19°, which showed no statistical significance) from the standing position[28]. For skeletally immature or maturing patients, SOSORT recommends X-rays every 6 to 12 months[29]. A radiologist blinded to the allocation of the patients was responsible for the follow-up.

Angle Trunk Rotation

ATR was measured using a scoliometer (Orthopaedic Systems Inc., Mizuho Ikakogyo Co., Tokyo, Japan). Scoliometer measurements showed a good correlation with the radiographic measurements (r = 0.7, $p < 0.05$)[30]. The patients were instructed to uncover the upper part of the body, sit on a chair, and bend the trunk forward to place the head and hands between the knees while keeping the shoulders and elbows straight. ATR was measured in the thoracolumbar area (T12-L1). The measurements were repeated until two consecutive ATR readings were identical[31].

Plantar Pressure Distribution

The static plantar pressure distribution of both feet was measured using a force distribution measurement system (Zebris Medical GmbH, Allgäu, Germany). The test-retest intraclass correlation coefficient of static plantar pressure measurements in children was considered excellent[32]. Each patient was instructed to stand barefoot on the platform, look forward straight ahead in an upright erect posture, with both arms beside the body and both feet separated slightly for 10 s. Measurements were collected from three valid trials and the mean was obtained for data analysis. Measurements of static plantar pressure were performed simultaneously for both the feet. The chart is presented as the total static plantar pressure (N/ cm^2)[33].

Functional Capacity

The functional capacity of each patient was evaluated using the six-minute walk test (6 MWT). The 6 MWT effectively demonstrated cardiorespiratory restrictions with the AIS[34]. The patient was asked to walk at a steady pace without running at maximal speed over 20 m on an unobstructed and rectangular pathway to cover as much distance as possible during 6 min. The researcher closely followed the patient while walking to ensure safety and measured the exact distance walked using a stopwatch.

Intervention

The patients in the Schroth group underwent the Schroth exercises, whereas those in the PNF group underwent the PNF technique. Each program was given for one hour with a 2-min rest period between each exercise, three days a week, for six successive months. The same researcher conducted each program. Eligible patients did not participate in other activities throughout the study and did not receive any injections or medications.

Before beginning the exercise, familiarity sessions to teach the patients the exercises were performed. Dropout was considered when the patient missed more than two sessions or did not complete more than 90% of the exercises. The authors checked the completeness of the interventions using the Template for Intervention Description and Replication (TIDieR) checklist and guide[35]. All patients were cooperative during the treatment sessions, and the adherence rate was approximately 98%.

Schroth Exercises

The exercises were performed using the RAB. The patient was instructed to breathe deeply during the self-correction of the curve to maximally expand the chest wall; during exhalation, the patient was asked to increase the activation by keeping all corrections. The exercises included the following.

A: Side-lying position (four sets × six repetitions)
The patient was asked to lie on the right side with passive support of a roll under the apex of the curve. To straighten the curve of the thoracic region, another roll was placed under the shoulder. The left upper limb (UL) was straightened and raised overhead, while the opposite limb was placed with a flexed elbow in front of the chest. The right lower limb (LL) with a 90° flexed hip and knee was rested on the floor. The pelvis was maintained perpendicular to each other. The left LL was rested on a stool in a stretched position. The patient was asked to self-correct the curve by pushing the convex side toward the concave side.

B: Sitting on a ball (four sets × six repetitions)
The patient sat on a Swiss ball in front of the wall bar. The left arm was abducted horizontally and held the bar of the wall at the same level as the shoulder with semi-flexed elbow while

the right UL was about 135° flexion and held the bar above the level of the shoulder with the elbow joint in a semi-flexed position. The patient was asked to self-correct the curve by pushing the convex side toward the concave side.

C: Shoulder counter-traction in prone (four sets × six repetitions)

In the prone position, the thoracic curve was corrected using shoulder counter-traction, while the lumbar curve was corrected *via* activation of the iliopsoas muscle.

D: Muscle cylinder in standing (four sets × six repetitions)

The goal of this exercise was to activate the quadratus lumborum on the lumbar concavity which helped to correct the lumbar curve. The patient stood on the right LL, while the left LL was abducted and stretched on a stool. The left hand held the hip. The right UL was straightened upward to align with the abducted opposite LL.

E: Cool down (four sets × six repetitions)

The patient was in a crook-lying position to fix the pelvis in a posteriorly tilted position. The patient was asked to perform repeated forward movements of the thoracolumbar junction with normal breathing. The researcher provided support to the spinal processes and felt an emerging movement.

Proprioceptive Neuromuscular Facilitation

It included the following patterns[25], and each exercise was performed in 2 sets × 10 repetitions:

- Deep breathing and pelvic posterior tilting from hook-lying position.
- Flexion, adduction, and external rotation pattern of the right LL with a flexion-abduction-external rotation of the right UL, from an amphibian position.
- Flexion pattern of both LL_S to the right with flexion, abduction, and external rotation of the right UL, from the supine position.
- Extension, abduction, and internal rotation of the left LL with flexion, abduction, and external rotation of the right UL, from a side-lying position.
- From the sitting position, anterior elevation of the right pelvis with extension, abduction, and internal rotation pattern of the left UL.
- From the standing position, anterior elevation of the right pelvis with extension, abduction, and internal rotation pattern of the left UL.

Statistical Analysis

SPSS version 25 (IBM SPSS, Armonk, NY, USA) was used to analyse the data. Patients' basic characteristics and Risser sign were compared between both groups using unpaired t-test and chi-square test, respectively. Shapiro-Wilk test was used to check the normal distribution of the data. Homogeneity between both groups was checked using Levene's test for homogeneity of variances. Mixed design MANOVA was performed to compare within-and between-group effects on Cobb's angle, ATR, 6 MWT, and total static plantar pressure. Subsequent multiple comparisons were performed using post-hoc tests. The level of significance for all statistical tests was set at $p < 0.05$.

Results

Basic Characteristics of the Patients

The basic characteristics of the patients in both groups are summarised in Table I. There was no significant difference between the groups in terms of age, weight, height, BMI, and Risser sign ($p > 0.05$).

Table I. Basic characteristics of the patients.

	Schroth group	PNF group	*p*-value
Age (yr)	14.50 ± 1.20	14.90± 1.40	0.38[a)]
Weight (kg)	53.30 ± 1.90	52.80 ± 1.60	0.41[a)]
Height (cm)	158.10 ± 1.30	158.6 ± 1.70	0.34[a)]
BMI (kg/cm^2)	19.25 ±1.23	19.90±1.60	0.19[a)]
Risser sign			
II	6 (35.29%)	5 (29.41%)	
III	5 (29.41%)	5 (29.41%)	0.62[b)]
IV	6 (35.29 %)	7 (41.17%)	

Values are presented as mean ± standard deviation or number (%). BMI, Body mass index; PNF, Proprioceptive neuromuscular facilitation. [a)] using *t*-test; [b)] using chi square test.

Effect of Treatment on Cobb's Angle, ATR, 6 MWT, and Total Static Plantar Pressure

Mixed MANOVA revealed a significant interaction between treatment and time (F = 159.86, p = 0.001). There were significant main effects of time and treatment (F = 403.33, p = 0.001 and F = 29, p = 0.001, respectively).

Within-Group Comparison

A significant decrease was noted in Cobb's angle and right total static plantar pressure with a significant increase in left total static plantar pressure post-treatment in both groups ($p < 0.001$). A significant increase in 6 MWT and decrease in ATR were recorded in the Schroth group ($p < 0.001$), with no significant change in the PNF group ($p > 0.05$).

Between-Group Comparison

Comparison of all measuring variables between the pre-treatment groups revealed no significant differences ($p > 0.05$), while post-treatment comparison revealed significant differences with superior effect to the Schroth group ($p < 0.001$) (Table II).

Discussion

This study aimed to investigate the effect of PNF and compared its effect with that of the Schroth exercises on scoliosis angle, static plantar pressure distribution, and functional capacity in AIS.

The results of this study revealed a significant decrease in Cobb's angle in both study groups. This result is in accordance with a study conducted by Kuru et al[11] which showed significant improvements in Cobb's angle, ATR, and quality of life following the Schroth exercises. Moreover, Park et al[23]conducted a meta-analysis and concluded that patients with AIS with Cobb angles of 10° to 30° may benefit from the Schroth exercises more than those with angles greater than 30°. Lee[25] conducted a pilot study to determine the influence of PNF exercises for six weeks on S-shaped curve IS in female patients in their early 20s. The observational spinal sways in the chest X-ray of the patients were corrected, and the static and dynamic balancing abilities improved compared to the baseline values.

The significant reduction in the Cobb's angle in the Schroth group might be attributed to the

Table II. Cobb's angle, ATR, 6MWT and total static plantar pressure pre and post-treatment of both groups.

	Schroth group	PNF group	*p*-value
Cobb's angle			
Pre-treatment	20.42 ± 2.57	20.21 ± 2.80	0.40
Post-treatment	14.11 ± 1.96	17.46 ± 2.37	0.001*
	p = 0.001*	p = 0.001*	
ATR			
Pre-treatment	8.05 ± 0.65	8.29 ± 0.68	0.31
Post-treatment	5.23 ± 0.43	8.17 ± 0.72	0.001*
	p = 0.001*	p = 0.39	
Left total static plantar pressure			
Pre-treatment	49.05 ± 1.14	48.94 ± 0.96	0.74
Post-treatment	53.58 ± 0.87	50.70 ± 0.98	0.001*
	p = 0.001*	p = 0.001*	
Right total static plantar pressure			
Pre-treatment	55.23 ± 1.03	55.70 ± 1.04	0.19
Post-treatment	51.29 ± 1.21	53.76 ± 1.14	0.001*
	p = 0.001*	p = 0.001*	
6MWT			
Pre-treatment	288 ± 9.73	283.70 ± 9.45	0.20
Post-treatment	328 ± 9.63	284.94 ± 11.29	0.001*
	p = 0.001*	p = 0.26	

Values are presented as mean ± standard deviation. ART, Angle trunk rotation; PNF, Proprioceptive neuromuscular facilitation; 6MWT, Six-minute walk test; *, significant at $p < 0.05$.

correction of the curve using the active derotation of the trunk segments achieved by RAB. This facilitation process starts with consciously repeated exercises with the help of feedback from the mirror that provided a mental re-education; finally, the corrected posture was recognised by a subconscious mind and could be carried out automatically. In addition, it enhances the flexibility and isometric endurance of the lumbar extensors of the spine[36].

The effect of PNF on Cobb's angle could be attributed to improvements in motor learning and control, muscle strength, and mobility. PNF entails task-oriented training aided by manual facilitation. It can improve the activity in motor centres by stimulating proprioceptors[19]. Comprehensive utilisation of muscular synergism maximally excites the weaker muscle groups on the convex side of the curve. A suitable position and correction in this position, the PNF technique prepares the patient to perform ADL_S with an optimally corrected spine and pelvis[20].

Decreasing ATR measurements is a critical aspect of exercise in AIS, resulting in greater spinal stability, improved breathing mechanics, and reduced possibility of curve progression[37]. The results of this study revealed a significant decrease in the ATR angle in the Schroth group, with no significant change in the PNF group. ART improvement in the Schroth group was supported by the findings of Yilmaz and Kuru[38], who revealed a 0.98° decrease in ATR measurements after three months of Schroth exercises. The ATR could be decreased because of the RAB through turning of the acromion of the ribs to the opposite which allowed the exercises to become more 3D and expand the thoracic cage. Moreover, Cobb's angle and pulmonary function could be improved simultaneously through the use of forced inspiration and expiration[21].

Scoliosis causes an imbalance of pressure on the soles which decreases with increasing Cobb's angle. Therefore, the recorded decrease in total plantar force on the right foot and an increase in the left foot may be related to increased symmetry. These results are consistent with those of Thabet[39]. Thus, the Schroth group in this study revealed a significant effect on weight loading compared to the PNF group because of its 3D scoliosis correction. The improved plantar pressure distribution in both groups might help provide normal foot biomechanics in the long-term.

Moreover, the results revealed a significant improvement in the 6 MWT in the Schroth group and a non-significant effect in the PNF group. The results of the Schroth group could be attributed to the significant improvement in foot pressure distribution and ART. The improvement in 6 MWT might be attributed to the improvement in respiratory functions, although they were not measured in this study. Furthermore, the trunk shape, thoracic wall function, and respiratory ability could be improved by applying RAB, which is an essential part of the Schroth exercises. Through contraction of the convex side, the inspired air is pushed toward the concave areas of the chest to stretch and mobilise the soft tissues in these areas[40]. This explanation is in accordance with the results of Otman et al[41] who reported that six months of Schroth exercise had a significant effect on the Cobb's angle and vital capacity. Moreover, the American Thoracic Society[42] stated several factors that might contribute to improvement in functional walking, such as increased stride length as well as behavioural and psychological factors. The increase in stride length may be due to improvement in cardiopulmonary efficiency, circulation, and biomechanical loading on the joints, while behavioural and psychological factors increase confidence and improve body image. Based on this, it could be assumed that 3D correction of scoliosis, reduction of the deformation of the rib cage, and improved foot pressure distribution could decrease the respiratory effort performed by the patients during walking and improve the 6 MWT of the Schroth group compared with the PNF group.

The study was restricted to include thoracolumbar curves only, which is a major limitation, since the usually less flexible thoracic curve is much more frequent in AIS. Although the sample number was in accordance with a previous statistical calculation, the small sample size is another limitation. Male patients with scoliosis were excluded from the study.

Conclusions

Based on the results obtained in this study, the PNF pattern program did not show a significant improvement in ATR measurements, which is a critical aspect of exercise rehabilitation in comparison to the Schroth exercises. These PNF patterns are not recommended for AIS correction. Long-term follow-up is needed to confirm the same results, and other studies should be conducted on other PNF techniques.

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Author Contribution Statements

Conceptualization: Rasha Abdelmoneim Mohamed, Abeer Mahmoud Yousef. Data curation: Abeer Mahmoud Yousef. Investigation: Rasha Abdelmoneim Mohamed, Abeer Mahmoud Yousef. Methodology: Rasha Abdelmoneim Mohamed, Abeer Mahmoud Yousef. Software: Rasha Abdelmoneim Mohamed. Writing-original draft: Rasha Abdelmoneim Mohamed. Writing-review, editing and Approval of final manuscript: Rasha Abdelmoneim Mohamed and Abeer Mahmoud Yousef.

Conflict of Interests

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