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Comparison of the efficacy of the Schroth method and proprioceptive neuromuscular facilitation technique in adolescent idiopathic Scoliosis: a randomized controlled, single-blinded study

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ABSTRACT

Background: The aim of this study was to evaluate and compare the effectiveness of the Schroth and PNF exercise methods concerning the Cobb angle, trunk rotation angle, quality of life, and aesthetic trunk deformity in adolescents diagnosed with idiopathic scoliosis.

Methods: This study employed a randomized, single-blind, 1:1 parallel-group design, involving a total of 67 adolescent patients. Participants were randomly allocated to either the Schroth group or the PNF group. Both groups participated in supervised exercise training sessions three times a week over a six-month period. Baseline and post-treatment assessments were conducted by the same researcher, who remained blinded to group allocations throughout the study. Statistical analysis was conducted using a mixed model for repeated measures ANOVA for each outcome measure.

Results: Statistical analysis revealed a significant difference between the groups in terms of the Cobb angle, trunk rotation angle (ATR), Scoliosis Research Society (SRS) scores, and Walter Reed Visual Assessment Scale (WRVAS) parameters ($p < .001$). The mean change scores indicated a statistically greater improvement in favor of the Schroth group across all parameters compared to the PNF group. Statistically significant changes were observed for all parameters within groups ($p < .05$).

Conclusions: The study compared the principles of the Schroth and PNF methods, demonstrating that the Schroth method achieved more favorable outcomes than PNF in the conservative management of adolescent idiopathic scoliosis. *This trial is registered with NCT05227638.*

1. Introduction

Adolescent Idiopathic Scoliosis (AIS) is characterized by a three-dimensional rotational distortion of the spine, typically involving a lateral deviation exceeding 10°, vertebral rotation, and diminished thoracic kyphosis (Grivas et al., 2006; Negrini et al., 2011). AIS is the most prevalent form of scoliosis, emerging during early puberty and affecting approximately 1–4 % of adolescents. Furthermore, it is more commonly observed in females aged 10–18 years (Cheng et al., 2015).

Several treatment modalities have been proposed for AIS, including exercise, bracing, casting, traction, biofeedback, and surgery. These interventions aim to correct, prevent, or halt the progression of spinal deformity (Hawes and O'brien, 2006; Weiss et al., 2006). Various exercise methods are employed in scoliosis management, such as the Schroth method, Barcelona Scoliosis Physical Therapy School (BSPTS), Side-Shift exercise, Lyon exercise, Scientific Exercise Approach to Scoliosis (SEAS), DoboMed, and Functional Individual Therapy of Scoliosis (Negrini et al., 2011; Lehnert-Schroth, 1992; Stępień et al., 2017a).

The Schroth method is a physiotherapeutic approach designed to treat scoliosis through isometric exercises and therapeutic movements, focusing on strengthening or lengthening asymmetrical muscles. This

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treatment regimen focuses on correcting scoliotic posture and employing specific breathing patterns, utilizing proprioceptive and exteroceptive stimuli, as well as mirror control techniques (Hawes and O'brien, 2006; Lehnert-Schroth, 1992). Studies have demonstrated the schroth method's effectiveness in reducing the Cobb angle, increasing muscle endurance, decreasing the need for surgery, and improving breathing function, pain, and body image compared to other conservative treatments such as observation and/or bracing (Schreiber et al., 2015; Park et al., 2017; Otman et al., 2005). However, its direct comparison with the Proprioceptive Neuromuscular Facilitation (PNF) method, which is not scoliosis-specific, has not yet been explored. This study addresses this gap by comparing these methods specifically for Lenke Type 1 thoracic curves. Detailed information about the Lenke classification system, including a schematic representation of curve types, is provided in Supplementary Table Lenke at the end of the manuscript.

The primary research question of this study is to determine the comparative effectiveness of Schroth and PNF methods in improving scoliosis-related outcomes in patients with Lenke Type 1 thoracic curves. The novelty of this study lies in its exclusive focus on a homogenous population, the inclusion of patient-reported outcomes Scoliosis Research Society-22 (SRS-22) and The Walter Reed Visual Assessment Scale (WRVAS), and its detailed evaluation of curve-specific therapeutic effects. This study also stands out for its integration of advanced curve-specific adaptations into therapeutic exercises, which align closely with the Lenke classification system. Furthermore, by emphasizing patient-centered outcomes such as quality of life and self-perception of deformity, this research provides a more holistic approach to understanding and managing AIS. These aspects collectively position the study as a significant contribution to the existing body of literature and a foundation for future research.

PNF is a therapeutic approach that uses movement patterns and specialized methods to enhance the range of motion. These patterns enable targeted interventions for specific areas of the body, including the spine, aiming to improve flexibility and function (Buck and Beckers, 2014). The reason for evaluating the PNF method in isolation is that the effectiveness of the Schroth method in treating adolescent idiopathic scoliosis has been well-documented in the literature. As a physiotherapeutic scoliosis-specific exercise protocol, the Schroth method was chosen as the most suitable comparator to assess the effects of PNF. This selection not only enhances the methodological rigor of our study but also allows for a clearer determination of the potential role of PNF in scoliosis management. However, PNF is not classified as one of the Physiotherapeutic Scoliosis-Specific Exercises and is less commonly used in scoliosis treatment. PNF is based on research suggesting that spinal curvature is linked to disruptions in the central nervous system (CNS). During development, such disruptions may lead to asymmetrical motor activity, resulting in improper spinal alignment. As spinal deformity progresses, it exacerbates functional asymmetry, which becomes normalized within the nervous system, causing individuals, particularly children, to lose sensitivity to proper body positioning (Domenech et al., 2011; Stępień et al., 2017b).

Mohamed et al. (Mohamed and Yousef, 2021) conducted a study involving 34 scoliosis patients treated using both the Schroth and PNF methods. Their findings indicated a decrease in the Cobb angle, particularly in the group treated with the Schroth method. Upper and lower extremity patterns were combined in their study. The present study aims to compare the effects of the Schroth and PNF methods in AIS patients to evaluate their therapeutic potential. Stepien et al. (Stępień et al., 2017a) employed the bilateral lower limb patterns of PNF along with the "contract-relax" method and asymmetrical breathing stimulation. Despite these interventions, they observed deviations from correction in the Trunk-Pelvis-Hip Angle and angle of trunk rotation (ATR).

According to the results of the aforementioned studies, the Schroth method appears to be effective in treating AIS. Conversely, the effectiveness of the PNF method, which is not specifically tailored for scoliosis, remains controversial in AIS treatment. The literature on PNF exercises for AIS is limited, with significant variability in the methods employed across different studies. Hence, the primary aim of the current study is to assess the comparative effectiveness of the Schroth and PNF methodologies when administered to individuals diagnosed with AIS.

2. Materials and method

2.1. Study design

This study utilized a randomized, single-blind, 1:1 parallel-group design and was conducted at the outpatient units of Kırşehir Ahi Evran University School of Physical Therapy and Rehabilitation from November 2021 to June 2022. The study proposal received approval from the local ethics committee (Decision: 2021–03/31). Prior to commencement, both written and oral consent were obtained from each participant and their families, given their adolescent status. The study adhered to the guidelines outlined in the Declaration of Helsinki and was registered under the code NCT05227638 on the "ClinicalTrials.gov" website.

2.2. Participants

Participants were adolescents diagnosed with AIS by a physician using the Lenke classification system, widely utilized for surgical planning and curve assessment. This system categorizes scoliosis based on coronal, sagittal, and rotational parameters. The study focused exclusively on Lenke Type 1 thoracic curves to ensure homogeneity in the study population. Participants were referred for exercise treatment at the School of Physical Therapy and Rehabilitation at Kırşehir Ahi Evran University.

Inclusion criteria: Adolescents aged 10–18 years who volunteered for participation, had a diagnosis of AIS, presented with a Cobb angle between 10° and 30°, exhibited a Risser sign of 0–3 (RISSER, 1958), and had thoracic curve involvement only (Slattery and Verma, 2018).

Exclusion criteria: Participants with non-idiopathic scoliosis, a history of spinal surgery, contraindications to exercise, rheumatological conditions, intellectual disabilities, or other neuromuscular disorders were excluded. A schematic representation of the Lenke classification system, included in the supplementary material, ensures compliance with ethical guidelines by not including patient-specific data.

2.2.1. Interventions

Both groups participated in supervised traditional exercises comprising stretching exercises targeting the concave side of the curve, posture training, breathing exercises, and spinal flexibility exercises. These exercises adhered strictly to the Schroth method's principles, excluding contraindicated bending movements for scoliosis management. Exercises were included in every session to maintain consistency, with progression based on each participant's functional improvement.

Session Details: Each session lasted 60 min, three times a week for six months, totaling 72 sessions per participant. Attendance records confirmed 100 % participation.

2.2.2. Schroth Group

Schroth Group (SG) underwent tailored Schroth exercises, combining passive and active postural self-correction exercises rooted in kinesthetic and sensorimotor principles. The primary objective was to enable patients to consciously maintain correct posture in daily activities (Lehnert-Schroth, 1992). These exercises incorporated strength and endurance training for postural muscles and aimed to reduce spinal curvature, improve self-image, and alleviate pain levels (Brink et al., 2017). Progression included transitioning from passive to active support and adapting exercises from lying to sitting and standing positions based on each patient's ability (Schreiber et al., 2015; Brink et al., 2017). Certified physiotherapists demonstrated and supervised these exercises to ensure proper method and adherence (ÖB). Patients were positioned asymmetrically to optimize trunk symmetry correction during Schroth exercises. The Schroth program encompassed rotational breathing, spinal extension, deflection, stretching, derotation, and strengthening exercises. These exercises aimed to enhance spinal curvature, muscle strength, and endurance of postural muscles. Rotational Angular Breathing (RAB) method, a core component of the Schroth method, was taught to participants under the guidance of a certified therapist and practiced regularly throughout the intervention period. This method focuses on rotational breathing exercises designed to actively correct thoracic curves by enhancing the expansion of the concave side of the rib cage, thereby improving spinal alignment and reducing curve severity. Various props such as bags of rice, foam blocks, a stool, and long sticks were utilized during Schroth exercises to facilitate posture correction and provide passive support. The intensity of Schroth exercises was progressively increased based on the patient's exercise performance improvement, achieved by reducing passive support, altering positions, and adjusting sets and repetitions.

2.3. Exercise list of schroth group

2.3.1. Shoulder counter-traction in prone position

To correct thoracic curvature, Schroth exercises employ deflection, which involves approaching or correcting the lateral deviation of the spine towards the midline, and derotation, achieved by applying opposite traction to the shoulders. These methods are implemented in various positions, including prone, supine, side-lying, and sitting. During rotational breathing, while exhaling, the thoracic convexity is pushed towards the midline, aiming to reverse the rotation of the spine. Simultaneously, maximum correction is sought through countertraction of the shoulder on the convex side.

Shoulder counter-traction in side-lying position: Similar to the previous exercise, but with the patient lying on their side.

Muscle cylinder in supine position: This exercise targets the deflection of thoracic and lumbar curvature by pushing the heel caudally and eccentrically working the Quadratus Lumborum muscle. It can be conducted with the patient lying on their side, in a half-lap position, or while standing. In the side-lying position, the patient lies on the thoracic concave side, with the arm on the concave side extended overhead to reduce compression in the thoracic concavity. A rice bag is placed on the lumbar region to correct lumbar curvature. The shoulder on the convex side is retracted, and the upper hand is positioned on the pelvis. The lower extremity is then extended caudally, with the foot slightly lifted from the ground to correct the lumbar concavity.

2.3.2. Shoulder counter-traction between two poles

The objective is to implement fundamental corrections while standing by employing countertraction of the shoulder girdle using sticks. These sticks are positioned perpendicular to the ground, with the convex side forearm placed adjacent to the stick, and the concave side positioned overhead with the arm extended straight. Once the exercise position is attained, pelvic corrections involving shift, tilt, and rotation, as well as correct weight transfer, are initiated. Axial elongation is performed, followed by basic correction movements such as deflection and derotation, requested from the patient according to the type of their curvature, accompanied by corrective/rotational breathing methods.

2.3.3. Schroth gait

In scenarios where the objective is to ensure continuity and stabilization of corrections under dynamic conditions, corrections are enacted in three planes subsequent to achieving the exercise position. While exhaling in accordance with the corrective/rotational breathing pattern, the patient is instructed to rise up on their fingertips and attain maximum axial elongation. This process is repeated with each forward step the patient takes.

2.3.4. Removing the stool

This exercise aims to strengthen the back and surrounding muscles by elongating the spine. Initially, the individual sits on a stool in front of a bar, assuming a cross-legged position and gripping the bar with their arms. Employing the corrective/rotational breathing pattern, the patient executes basic corrections while exhaling, maintaining this position for 3–4 breaths as the stool supporting them is gradually removed.

2.3.5. Proprioceptive Neuromuscular Facilitation Group

Proprioceptive Neuromuscular Facilitation Group (PNF-G) Each exercise in the subsequent patterns was conducted in two sets, comprising 10 repetitions per set. The PNF exercises were supervised and applied by a physiotherapist (BB) with >10 years' experience in this field. The chopping and lifting exercises were performed asymmetrically, targeting the convex side of the spinal curve to promote postural alignment. The contralateral side was stabilized to avoid further imbalance. The PNF exercises were as follows.

- Chopping exercise: This involves a combined movement where the patient stands, holds their left hand with their right, raises the hand diagonally to the head, and performs spinal rotation while lifting.
- Lifting exercise: Similar to the chopping exercise, the patient stands and returns to the first position with vertebral rotation by holding their right hand with their left, opposite to the side in the chopping exercise.
- Transitioning the arm: The arm transitions from a position of flexion, adduction, and external rotation to extension, adduction, and internal rotation while in the seated position.
- Retraction and depression of the scapula: Performed while the patient is lying on their left side.

2.4. Outcome measurements

At the baseline assessment, sociodemographic data of the participants, including age, height, weight, Body Mass Index (BMI), gender, and comprehensive medical history, were documented.

2.5. Cobb angle

Before the study commenced, an anteroposterior X-ray of the patient's entire spine was taken in a standing position. A second anteroposterior X-ray was taken after the 6-month treatment period to evaluate changes in the Cobb angle. Scoliosis grades were evaluated according to the Cobb method (Pruijs et al., 1994).

2.6. Angle of trunk rotation

The ATR was measured with the patient in both a standing and forward-bending position using a Scoliometer, with the highest trunk rotation angle recorded (Amendt et al., 1990). This measurement was repeated after the 6-month treatment period to evaluate changes in trunk rotation.

2.6.1. Quality of life

The SRS-22 questionnaire evaluates the health-related quality of life tailored to individuals with scoliosis. This questionnaire was administered at baseline and after the 6-month treatment period to assess changes in health-related quality of life. It is a Likert-type instrument that gauges patients' function/activity, mental health, body image, treatment satisfaction, and pain. Comprising 22 items, each scored on a scale from "1" (worst) to "5" (best), the questionnaire generates a composite score at the conclusion, ranging from "1" (indicating very poor quality of life) to "5" (representing optimal quality of life) (Asher et al., 2003).

2.7. Cosmetic trunk deformity

The patients' cosmetic trunk deformity was evaluated using the WRVAS, a Likert-type instrument designed to assess the perceived physical deformity in patients with idiopathic scoliosis based on their self-description of deformity. The WRVAS evaluates seven visible aspects of spinal deformity: shoulder level, body curve, head–pelvis alignment, flank prominence, rib prominence, scapular rotation, and alignment of head, rib, and pelvis. Scores for each category range from "1" (no deformity) to "5" (the most severe deformity), with a total score derived from the sum of scores across all seven domains (Sanders et al., 2003). The WRVAS has demonstrated high reliability and validity for AIS patients in evaluating their self-perception of deformity (ÇOLAK and ÇOLAK, 2020). This evaluation was conducted at baseline and repeated after the 6-month treatment period to assess changes in the perception of deformity.

2.7.1. Sample size

The sample size for the study was determined using the G*Power program, version 3.1.9.4 (Heinrich Heine University, Düsseldorf, Germany) (Kocaman, 2021). Based on findings from previous studies, which indicated small to moderate effects of exercises on the Cobb angle of the main curve (effect sizes ranging from 0.16 to 0.38) (Kuru et al., 2016; Białek, 2011) the study aimed to achieve 80 % statistical power (1 - β error probability) with a significance level of 0.05 (α error probability). Repeated measures analysis of variance (ANOVA) was employed for within- and between-group interactions, utilizing a medium effect size of 0.3 to account for the two groups, two measurements for the primary outcome, and generating a sample size of 68 participants. To accommodate a 15 % dropout rate, a total of 80 participants were included in the study.

2.7.2. Randomization and blinding

The participants were randomly divided into two groups based on age and Cobb angle, utilizing matched randomization performed through Research Randomizer (https://www.randomizer.org/), an online tool for randomization (Available from). The target sample size was calculated as 68 participants to achieve 80 % statistical power, but we aimed to recruit 82 participants to account for an anticipated dropout rate of approximately 15 %. Ultimately, 82 patients were initially enrolled; however, 15 patients dropped out during the study period, resulting in a final sample size of 67 participants (SG: 34, PNF-G: 33). A post-hoc power analysis revealed a revised statistical power of 79.7 %, ensuring the robustness of the findings. All evaluations at baseline and after the 6-month treatment period were carried out by the same researcher (MHK), who remained blinded to the group allocations throughout the study.

2.8. Statistical analysis

Statistical analyses were conducted using IBM's SPSS software (version 24). The normality of variables was assessed using both visual (histograms and probability plots) and analytical (Shapiro-Wilk tests) methods. Descriptive statistics were presented using mean and standard deviation for normally distributed variables, and numbers and percentages for nominal variables. Student's t-test was used to compare mean values between the PNF-G and SG. The relationship between categorical variables was examined using the chi-square test (Pearson chi-square). Repeated measures analysis was performed using two-way analysis of variance (Mixed design repeated measures ANOVA) to evaluate changes over time and interactions between time and group for measured variables in the PNF-G and SG. The significance level was set at 5 % for statistical significance.

3. Results

The flowchart depicting the study is illustrated in Fig. 1. Initially, 122 patients diagnosed with AIS were admitted to the department. Among them, 82 patients fulfilled the inclusion criteria for the study. They were then randomized, with 41 patients allocated to the SG and 41 patients to the PNF-G. Finally, the study concluded with 34 patients in the SG and 33 patients in the PNF-G.

As shown in Table 1 the physical and demographic characteristics of both the SG and PNF-G. Statistical analysis indicated no significant difference between the SG and PNF-G concerning their demographic and physical characteristics ($p > .05$). This suggests that the two groups were comparable in terms of the distribution of participants' demographic and physical attributes.

Table 2 presents the baseline measurements, post-treatment values, and changes in scores for the Cobb angle, ATR, SRS-22, and WRVAS parameters for both the SG and PNF-G.

According to the two-way mixed design repeated-measures ANOVA analysis, a statistical difference was observed for the Cobb angle, ATR, SRS-22 scores, and WRVAS parameters when analyzing the change over time between the groups (Group*Time interaction) ($p < .05$). Specifically, the SG demonstrated a statistically higher change compared to the PNF-G for all parameters (refer to Table 2). However, when examining changes within the groups (within-group Time main effect), a statistical difference was found for all parameters ($p < .05$).

4. Discussion

In this study, we investigated the effects of Schroth exercises and the PNF method on scoliosis curve severity, quality of life, angle of trunk rotation, and cosmetic trunk deformity in patients with AIS. Both approaches demonstrated positive effects on scoliosis curve severity, quality of life, angle of trunk rotation, and cosmetic trunk deformity. However, the Schroth method showed greater effectiveness compared to PNF in improving curve severity, quality of life, trunk rotation angle, and cosmetic trunk deformity. Its emphasis on curve-specific adaptations aligns closely with the Lenke classification system, facilitating targeted and precise interventions for Lenke Type 1 thoracic curves. By tailoring exercises to the unique characteristics of these curves, the Schroth method optimizes outcomes for patients. One of the primary objectives of exercise regimens recommended for individuals with AIS is to reduce the severity of spinal curvature (Negrini et al., 2008). While many studies have shown the Schroth method to significantly decrease the severity of thoracic curves in AIS patients (Kuru et al., 2016; Kocaman et al., 2021; Kim and HwangBo, 2016; Gür et al., 2017), only a limited number of studies have reported positive effects of the PNF method on spinal curvature (Mohamed and Yousef, 2021; Lee, 2016). In the present study, both the Schroth and PNF methods effectively reduced the severity of scoliotic curvature in patients with AIS. However, the SG achieved more favorable results in terms of patients' Cobb angle compared to the PNF-G. The calculated effect sizes (η^2) further highlighted the superior efficacy of the Schroth method, demonstrating its greater impact on curve severity and other outcomes. In a study conducted by Mohamed et al. (Mohamed and Yousef, 2021) involving 34 AIS patients, it was reported that the Cobb angle decreased from 20° to 14° with the Schroth method and from 20° to 17° with the PNF method. These findings indicate that the Schroth method is more effective than PNF in reducing the Cobb angle. Our findings are consistent with Mohamed et al.'s study, which also demonstrated greater improvements in the Cobb angle with the Schroth method compared to PNF. However, our study uniquely focuses on Lenke Type 1 thoracic curves and includes patient-reported outcomes, such as quality of life and self-perception of deformity, providing a more comprehensive evaluation of therapeutic effects. This alignment with previous literature underscores the consistent efficacy of these approaches. Although PNF is not specifically tailored for scoliosis, studies have suggested its

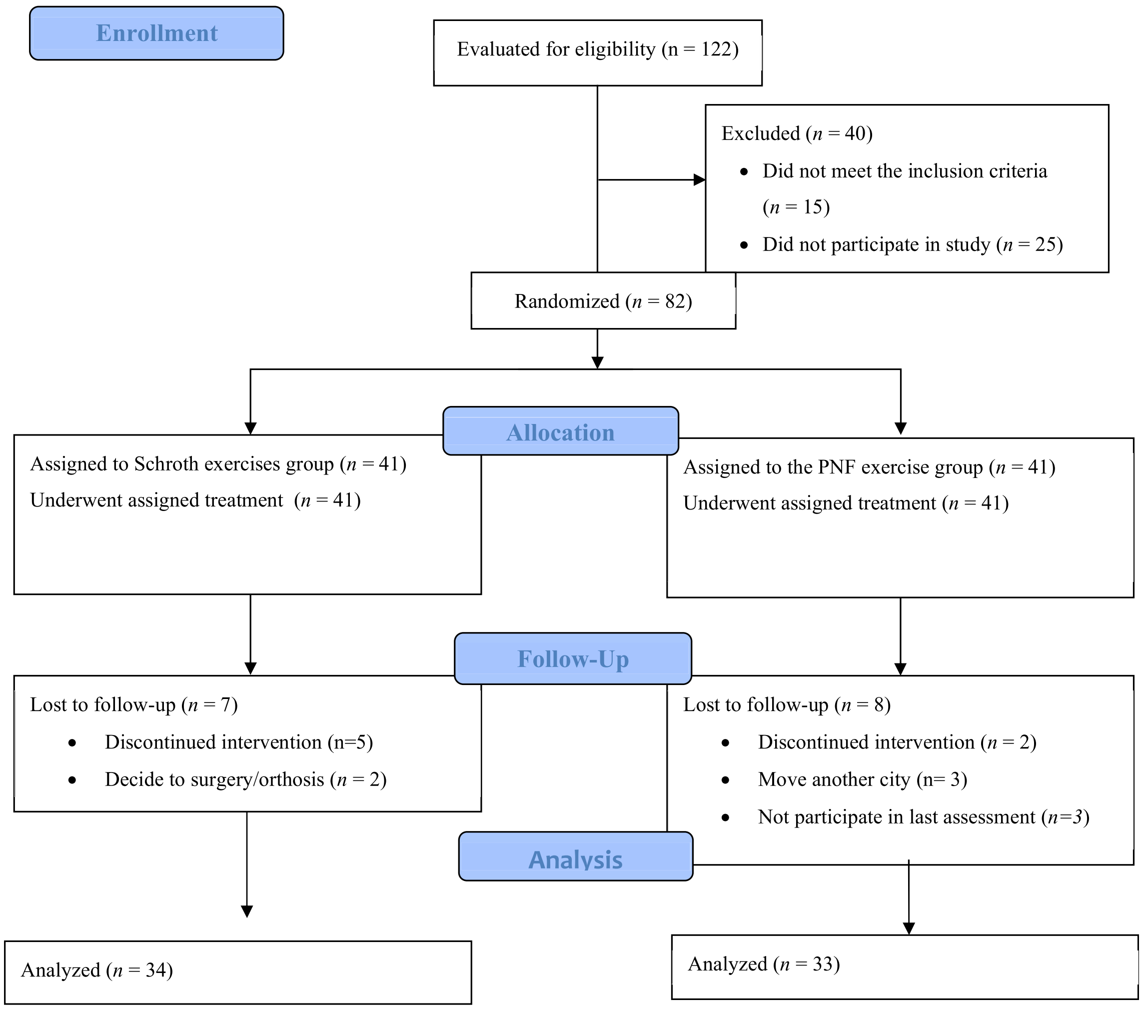

Fig. 1. Flowchart of the study.

Table 1
Comparison of the physical and demographic attributes of the two groups.

		SG (*n* = 34)		PNF-G (*n* = 33)		*t*	*p*
		X ± SD		X ±SD			
Age (years)		13.8 ± 1.6		14.1 ± 1.8		−0.452	0.645
Height (cm)		156.4 ± 6.8		157.5 ± 5.7		−0.708	0.482
Weight (kg)		54.2 ± 8.3		54.1 ± 7.3		0.065	0.948
BMI (kg/m^2)		22.3 ± 2.9		21.9 ± 2.3		0.489	0.642
		n	**(%)**	***n***	**(%)**	**X^2**	***p***
Gender	Female	24	70.6	25	75.3	1.181	0.277
	Male	10	29.4	8	24.3		

BMI: Body Mass Index, Student T Test, X^2: Chi-square Analysis, M: Mean, SD: Standard Deviation, SG: Schroth Group, PNF-G: Proprioceptive Neuromuscular Facilitation Group.

potential benefits in improving neuromuscular coordination and functional flexibility (Stępień et al., 2017a; Lee, 2016). For example, PNF methods are known to enhance proprioceptive feedback and muscle activation patterns, which may indirectly contribute to better postural alignment in AIS patients. However, as the current study demonstrated, these effects are less pronounced compared to the targeted outcomes achieved by the Schroth method. Future research could investigate the

Table 2
Baseline, post-treatment scores, and percentage changes for Cobb, ATR, SRS-22, and WRVAS parameters.

Parameter	Cobb Angle (°)	SRS-22	ATR (°)	WRVAS
SG Baseline	16.2 ± 2.7	4.4 ± 0.2	4.5 ± 1.4	13.7 ± 3.5
SG Post Treatment	10.4 ± 4.6	4.0 ± 0.4	2.6 ± 1.2	8.9 ± 3.2
% Change (SG)	**−35.8 %**	**−9.1 %**	**−42.2 %**	**−35.0 %**
PNF-G Baseline	17.2 ± 4.2	4.0 ± 0.5	4.6 ± 1.7	11.5 ± 2.9
PNF-G Post-Treatment	15.0 ± 4.1	4.0 ± 0.4	4.3 ± 1.4	10.6 ± 2.7
% Change (PNF-G)	**−12.8 %**	**0 %**	**−6.5 %**	**−7.8 %**
The difference in score change between the two groups *(M)*	3.98	0.18	1.09	2.83
Time (p) (main effect)	<0.001	<0.001	<0.001	<0.001
Group*Time Interaction (p) F/*p value* (Interaction)	16.41/< **.001**	22.74/< **.001**	37.48/< **.001**	20.50/< **.001**
η^2	0.57	0.27	0.38	0.25

2-way mixed design repeated-measures analysis of variance, M: Mean, SD: Standard Deviation, η^2: Effect size, WRVAS: Walter Reed Visual Assessment Scale, SRS-22: Scoliosis Research Society, PNF: Proprioceptive Neuromuscular Facilitation, ATR: Trunk Rotation Angle, PNF-G: PNF group, SG: Schroth Group.

integration of PNF with scoliosis-specific exercises to determine if a combined approach yields superior outcomes.

Current literature suggests that patients with AIS undergoing the Schroth method exhibit significant improvements in ATR asymmetries (Kuru et al., 2016; Kocaman et al., 2021; Kim and HwangBo, 2016; Gür et al., 2017). Conversely, several studies have indicated that the PNF method reduces trunk rotation asymmetry in AIS patients. For instance, in a study conducted on 83 AIS patients (Stępień et al., 2017a), the PNF method reduced thoracic ATR from 7.96° ± 0.75°–5.71° ± 0.61° and lumbar ATR from 4.90° ± 0.39°–3.23° ± 0.33°. Similarly, Mohamed et al. (Mohamed and Yousef, 2021), compared the effects of the Schroth and PNF methods on ATR, reporting reductions from 8.05° ± 0.65°–5.23° ± 0.43° in the SG and from 8.29° ± 0.68°–8.17° ± 0.72° in the PNF-G (These values are given as mean ± standard deviation (SD). In the current study, both the Schroth and PNF methods effectively reduced ATR in AIS patients, with the Schroth method demonstrating superior outcomes. While Mohamed et al.'s study included a mixed cohort of thoracolumbar and thoracic curves, this study exclusively focused on Lenke Type 1 thoracic curves. This intentional selection ensured homogeneity in the study population, enabling a more precise evaluation of the methods' effects on this specific curve type. Additionally, Mohamed et al. primarily reported outcomes related to curve severity and trunk asymmetry, whereas the present study expanded its scope to include patient-reported outcomes such as SRS-22 and WRVAS. These additional parameters provided a more holistic understanding of the therapeutic impacts of the Schroth and PNF methods. This study stands out as one of the pioneering comparative analyses of the Schroth and PNF methods in treating AIS, with a specific focus on thoracic curves. While the Schroth method is well-documented for reducing curve severity, enhancing quality of life, and improving trunk symmetry, this study highlights the complementary role of PNF exercises. Despite being less specific to scoliosis management, PNF exercises contribute to functional improvements in flexibility, muscle balance, and postural alignment. This finding underscores the potential of integrating PNF methods with Schroth exercises to maximize therapeutic outcomes in AIS patients. Furthermore, this study contributes novel insights to the literature by focusing on Lenke Type 1 thoracic curves and integrating patient-reported outcomes such as SRS-22 and WRVAS. These aspects, combined with a detailed evaluation of curve-specific therapeutic effects, distinguish our findings from previous research and provide a robust framework for future studies. Future research could explore the integration of PNF with scoliosis-specific exercises to determine if a combined approach yields superior outcomes. While PNF has shown less effectiveness compared to the Schroth method, it holds potential in enhancing neuromuscular coordination and functional flexibility. On the other hand, the Schroth method demonstrates strong efficacy in directly improving scoliosis curve severity, quality of life, and perception of deformity through its curve-specific adaptations. In this context, it is hypothesized that integrating PNF with the Schroth method could optimize neuromuscular activation and postural alignment. Specifically, the proprioceptive feedback and muscle activation properties of PNF, when combined with the curve-specific correction strategies of the Schroth method, might produce more effective outcomes. Therefore, future studies should investigate the potential synergy between these two methods and evaluate whether a combined treatment protocol offers superior results compared to the Schroth method alone. Such a combined therapy approach has the potential to improve both physiological and psychosocial outcomes in patients with AIS.

The perception of deformity in scoliosis can significantly impact self-confidence, quality of life, and body image. Furthermore, the severity of the Cobb angle and trunk asymmetry are key factors influencing individuals' perception of their deformity (Rumsey and Harcourt, 2004). While numerous studies in the literature have investigated the perception of deformity in AIS patients using the Schroth method (Kocaman et al., 2021; Çolak et al., 2017), none have examined this effect in the context of the PNF method. In the present study, both the Schroth and PNF methods were found to reduce the perception of deformity in AIS patients. However, the Schroth method demonstrated greater effectiveness in achieving this outcome. This study is particularly noteworthy as it is the first to evaluate the impact of the PNF method on the perception of deformity in AIS patients.

The study also observed that both the Schroth and PNF methods improved the quality of life of patients across both study groups. While both exercise methods produced positive changes in the quality of life for AIS patients, the Schroth method exhibited superior outcomes compared to the PNF method. Existing literature on the impact of conservative treatments on the quality of life in scoliosis patients has presented mixed results. Some studies have reported significant improvements in life quality due to exercise protocols, whereas others have found no substantial effects (Kuru et al., 2016; Kwan et al., 2017). These discrepancies may stem from variations in the tools and metrics used to evaluate quality of life.

Several limitations of this study should be acknowledged. Firstly, the study exclusively included individuals with Lenke Type-1 spinal curvature, thereby restricting the generalizability of the findings to other curvature types. Moreover, sagittal profile analysis was not incorporated into this study. The primary focus was on evaluating the effects of Schroth and PNF methods on thoracic curves in AIS. Future studies could integrate sagittal profile analysis to offer a more comprehensive understanding of spinal morphology and its interplay with these interventions. Secondly, the treatment program included only individuals with mild or moderate thoracic curvature, leaving the effectiveness of the two exercise methods for patients with more severe curvature levels unknown. Thirdly, the study concentrated solely on AIS patients, and the applicability of these exercise programs across different age groups remains unclear. Lastly, despite accounting for a 15 % dropout rate, the study was completed with 67 patients instead of the planned 68. A post-hoc power analysis revealed that this marginal reduction resulted in a revised power of 79.7 %.

5. Conclusion

Based on the findings of this study, both the Schroth and PNF exercise methods effectively reduced the severity of the curve in patients with AIS, improved their quality of life, and decreased their perception of trunk rotation asymmetry. However, the Schroth method demonstrated more favorable outcomes compared to the PNF method. These results emphasize the benefits of both exercise methods in improving curvature severity, deformity perception, trunk rotation asymmetry, and quality of life in AIS patients. The study's contributions are significant as it provides a focused analysis of Lenke Type 1 thoracic curves, integrates patient-reported outcomes into scoliosis research, and underscores the importance of curve-specific therapeutic adaptations. These novel insights offer a robust framework for enhancing conservative management strategies in AIS and addressing existing gaps in the literature.

Nonetheless, further research is needed, particularly to evaluate the effectiveness of these methods in populations with more severe curvatures, other types of spinal curvature, and varying forms of idiopathic scoliosis. **In particular, future studies should focus on investigating the effects of the PNF method alone by including only a PNF group and a control group**. Future studies could also explore the long-term outcomes and integration of these methods with other treatment modalities to provide a comprehensive approach to managing AIS.

CRediT authorship contribution statement

Mehmet Hanifi Kaya: Writing – review & editing, Writing – original draft, Data curation. **Öznur Büyükturan:** Investigation, Formal analysis, Conceptualization. **Buket Büyükturan:** Validation, Supervision. **Halil Alkan:** Validation, Supervision, Software. **Fatih Erbahçeci:** Writing – review & editing, Writing – original draft, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbmt.2025.04.003.

Appendix

Table Lenke's Criteria for Curve Classification.

Type	Curve	Proximal Thoracic	Main Thoracic	Thoracolumbar/Lumbar
1	Main thoracic	Not structural	Structural*	Not structural
2	Double thoracic	Structural	Structural*	Not structural
3	Double major	Not structural	Structural*	Structural*
4	Triple major	Structural	Structural*	Structural*
5	Thoracolumbar/lumbar	Not structural	Not structural	Structural*
6	Thoracolumbar/lumbar-main thoracic	Not structural	Structural*	Structural*

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