Game Nexus

The Effects of Two Schroth and Modified Schroth Exercise Programs on Cobb Angle, Spinal Mobility, and Pain in Adolescents with Idiopathic Scoliosis

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ABSTRACT

One of the spinal disorders is adolescent idiopathic scoliosis. The purpose of this study was to examine the effects of two Schroth and modified Schroth exercise programs on the Cobb angle, spinal mobility, and pain in adolescents with idiopathic scoliosis. The study was applied in terms of purpose. The statistical population consisted of boys aged 10 to 15 years with scoliosis, from whom 40 participants were selected using stratified block randomization. The participants were allocated into three groups (two intervention groups and one control group). To assess spinal mobility and pain intensity (VAS), X-ray radiography and a grid board, and the Visual Analog Scale (VAS) questionnaire were used, respectively. The exercise programs were performed for 45 minutes per day, 5 days per week, over a period of 12 weeks by the exercise groups. The results showed that Schroth and modified Schroth exercises had a significant effect on the Cobb angle ($P = 0.000$), that Schroth and modified Schroth exercises had a significant effect on spinal mobility ($P = 0.000$), and that Schroth and modified Schroth exercises significantly affected pain intensity in adolescents ($P = 0.000$). Moreover, the effect of modified Schroth exercises on reducing the Cobb angle ($P = 0.001$) and reducing spinal pain ($P = 0.004$) was greater than that of the Schroth exercise group, while the effects of modified Schroth and Schroth exercises on spinal mobility were similar ($P = 0.789$). It is recommended that corrective exercise specialists, therapeutic exercise professionals, and physiotherapists use specialized Schroth exercises and related modified Schroth exercises to correct scoliosis and reduce the complications associated with this deformity.

Keywords: Schroth and modified Schroth exercises; mobility; Cobb angle; pain; spine; scoliosis; adolescents.

Introduction

Adolescent idiopathic scoliosis (AIS) is one of the most common musculoskeletal deformities of the spine during growth, characterized by a three-dimensional deviation involving lateral curvature, vertebral rotation, and sagittal plane alterations. This condition typically emerges during the rapid growth period of adolescence and affects physical structure, functional capacity, respiratory mechanics, and psychosocial well-being. Epidemiological evidence suggests that AIS affects approximately 2–4% of adolescents worldwide, with a higher prevalence and progression risk observed during pubertal growth spurts. If left untreated or inadequately managed, scoliosis may progress and lead to chronic pain, postural asymmetry, reduced spinal mobility, compromised pulmonary function, and long-term reductions in quality of life (1-3). Consequently, early detection and evidence-based conservative interventions remain central priorities in physical education, rehabilitation sciences, and corrective exercise disciplines.

From a biomechanical perspective, scoliosis alters load distribution along the spinal column, influencing flexibility, proprioception, and neuromuscular control. Changes in spinal stiffness and soft tissue properties can significantly affect movement efficiency and postural regulation, thereby increasing the risk of pain and functional limitations (4, 5). Moreover, segmental curve flexibility has been identified as a key predictor of scoliosis progression and treatment responsiveness, underscoring the importance of interventions that target spinal mobility and active self-correction (6). Accurate assessment of scoliosis severity traditionally relies on radiographic evaluation using the Cobb angle, which remains the gold standard despite the development of alternative measurement techniques (7). The Cobb angle provides essential clinical information for diagnosis, treatment planning, and monitoring outcomes in both conservative and surgical approaches.

Conservative management of AIS has evolved substantially over recent decades, shifting from passive observation and bracing toward active exercise-based rehabilitation. While bracing remains effective in preventing curve progression in certain cases, it may be associated with adverse biomechanical and sagittal alignment consequences, as well as psychological burden and reduced compliance among adolescents (8, 9). These limitations have stimulated growing interest in physiotherapy scoliosis-specific exercises (PSSE), which emphasize active spinal correction, postural awareness, muscle symmetry, and functional integration. Comprehensive reviews have identified several major schools of PSSE, including the Schroth method, each with distinct theoretical foundations and practical applications (10, 11).

The Schroth method, originally developed as a three-dimensional corrective approach, is among the most widely studied and clinically implemented exercise systems for AIS. It focuses on individualized correction based on curve pattern, incorporating rotational angular breathing, postural re-education, and targeted muscle activation to achieve spinal elongation and derotation (12). The theoretical rationale of Schroth exercises is grounded in neuromuscular re-patterning and sensorimotor integration, aiming to improve proprioception, trunk stability, and voluntary control of posture. Empirical studies and randomized controlled trials have demonstrated that Schroth exercises can significantly reduce Cobb angle, improve spinal alignment, enhance pulmonary function, and alleviate pain in adolescents with idiopathic scoliosis (13-15).

Beyond structural outcomes, Schroth-based interventions have been shown to positively influence health-related quality of life, functional capacity, and psychological well-being. Improvements in body image, self-efficacy, and perceived physical competence have been reported, highlighting the multidimensional benefits of active corrective exercise approaches (16, 17). Furthermore, the integration of breathing techniques within Schroth exercises plays a crucial role in addressing respiratory limitations commonly associated with thoracic scoliosis, particularly in moderate curves (1, 18).

Despite the documented efficacy of traditional Schroth exercises, recent research has emphasized the need for methodological refinement and program modification to enhance clinical outcomes. Modified Schroth protocols often incorporate additional strengthening, stabilization, and corrective components targeting the trunk, pelvis, and lower extremities. These adaptations aim to address global postural chains, improve dynamic balance, and facilitate transfer of corrective postures into functional activities. Evidence from comparative and combined-intervention studies suggests that integrating core stabilization, balance training, and functional strengthening with scoliosis-specific exercises may yield superior outcomes in pain reduction and postural control (19-21).

Spinal mobility is another critical functional parameter in adolescents with scoliosis, influencing movement efficiency, daily activity performance, and long-term musculoskeletal health. Reduced flexibility and asymmetrical motion patterns are frequently observed in AIS and are associated with higher pain intensity and functional limitations (3). Exercise-based interventions that emphasize controlled movement, elongation, and segmental dissociation have been shown to improve spinal mobility and balance. Pilates-based programs, core stabilization exercises, and task-oriented training have demonstrated beneficial effects on spinal alignment and functional outcomes, particularly when combined with scoliosis-specific principles (22-24).

Pain, although not always the primary clinical manifestation of AIS during adolescence, represents an important outcome variable due to its association with reduced participation in physical activity and diminished quality of life. Neuromuscular adaptations, altered proprioception, and muscle imbalance contribute to pain perception in scoliosis, suggesting that interventions targeting sensorimotor control and central processing may be particularly effective (5, 25). Emerging evidence from rehabilitation neuroscience indicates that exercise-induced neuroplasticity plays a key role in pain modulation, supporting the use of structured therapeutic exercise programs for musculoskeletal disorders (25, 26). Within this framework, Schroth and modified Schroth exercises may exert their analgesic effects not only through mechanical correction but also via central adaptations related to motor control and pain processing.

Technological advances have further enhanced the assessment and monitoring of scoliosis-related outcomes. Non-invasive posture evaluation methods, including computer vision and movement analysis systems, have improved the precision of postural and mobility assessments while reducing reliance on repeated radiographic exposure (27). These developments align with contemporary physical education and rehabilitation paradigms that emphasize functional assessment and movement quality alongside traditional structural measures.

Although a growing body of literature supports the effectiveness of Schroth-based interventions, several gaps remain. Notably, comparative evidence between standard Schroth and modified Schroth exercise programs remains limited, particularly with respect to simultaneous evaluation of structural (Cobb angle), functional (spinal mobility), and subjective (pain) outcomes in adolescent populations. Previous studies have often focused on single outcomes or combined interventions, making it difficult to isolate the relative efficacy of modified protocols (28, 29). Additionally, variability in exercise dosage, duration, and participant characteristics underscores the need for further controlled trials to refine best-practice guidelines.

Given the central role of physical education specialists, corrective exercise practitioners, and physiotherapists in the non-surgical management of AIS, robust comparative evidence is essential for informing clinical decision-making and program design. Understanding whether modified Schroth exercises provide added benefits over traditional Schroth protocols in reducing spinal curvature, enhancing mobility, and alleviating pain has direct implications for individualized treatment planning and long-term functional outcomes.

Therefore, the aim of the present study was to compare the effects of Schroth and modified Schroth exercise programs on Cobb angle, spinal mobility, and pain in adolescents with idiopathic scoliosis.

Methods and Materials

In this applied study, the primary objective was to investigate the effects of two different exercise programs (Schroth and modified Schroth) on Cobb angles, spinal mobility, and pain in adolescents with idiopathic scoliosis aged 10 to 15 years. The research design was quasi-experimental, employing a pretest–posttest approach with three experimental groups, including two intervention groups and one control group. The statistical population comprised all boys aged 10 to 15 years with scoliosis, from whom a sample of 45 students was purposively and conveniently selected from schools in Qazvin Province. These participants were randomly assigned to three groups of 15 individuals each: two intervention groups (Schroth and modified Schroth) and one control group. Inclusion criteria included boys with scoliosis presenting an S-shaped lateral curvature of 10 to 20 degrees, no history of spinal surgery, no use of braces, and no structural shortening of the lower limbs. Exclusion criteria included participation in regular sports activities during the study period, presence of respiratory or cardiovascular problems, sports injuries within the past 6 months, lack of cooperation in the study, and absence from more than two training sessions.

Data in this study were collected using two methods: library-based (review of scientific sources, books, internet resources, and relevant articles) and field-based (data collection through various measurement instruments). Accordingly, measurement tools included a scale for body weight measurement (Sarto model), a digital stadiometer for height measurement (Digital Stadiometer), the Visual Analog Scale (VAS) questionnaire for pain intensity assessment, radiographic imaging (X-ray) for Cobb angle assessment, the Adams forward bend field test for scoliosis detection, and a grid board for assessing spinal mobility. Radiographic imaging (X-ray) was used to measure the Cobb angle, a method recognized as a standard and valid approach for determining scoliosis severity. Measurement of the Cobb angle involved estimating the angle between two tangent lines drawn along the upper and lower vertebrae of the spinal curve. The Adams forward bend test was conducted to determine the type of scoliosis (functional or structural). In this test, the participant bent forward to allow evaluation of spinal curvature. The pain questionnaire (VAS), a well-established tool for assessing pain intensity, is designed as a 10-cm line, and in this study pain intensity was evaluated on a scale from 0 to 10. The validity and reliability of this questionnaire have been confirmed in various studies. In addition, a grid board was used to assess spinal mobility, with evaluation performed from a distance of approximately 3 meters while the participant was standing in a natural posture.

In the initial phase of the study's implementation procedure, the samples were divided into three experimental groups. First, pretests were conducted for all participants to measure scoliosis, spinal mobility, pain intensity, and Cobb angle. Subsequently, the experimental groups performed their respective exercise programs for 12 weeks as follows: the Schroth group performed strengthening exercises for the interscapular muscles and the vertical and transverse muscles, along with breathing exercises, for 45 minutes per day, 5 days per week. The modified Schroth group, in addition to Schroth exercises, performed corrective exercises to strengthen other body muscles, including the abdominal, back, neck, and plantar flexor muscles. The control group received no intervention during this period and continued their daily activities. After completion of the training sessions, posttests similar to the pretests were administered for all groups. The collected data were then transferred to the next stage for analysis. Data analysis was conducted using descriptive statistics (frequency, percentage, mean, standard deviation, and standard error) and inferential statistics, including the Shapiro–Wilk test to examine data normality and analysis of covariance (ANCOVA) to analyze the effects of variables. Between-group comparisons were also performed using the independent t-test. All data were analyzed using SPSS software version 27 at a significance level of 0.05.

Figure 1. Assessment of spinal mobility

Figure 2. Assessment of scoliosis

Table 1. Twelve-week Schroth and Modified Schroth Exercise Programs

Week	Type of Exercise	Exercise Name	Sets and Repetitions	Exercise Objective
Weeks 1–4	Interscapular muscle strengthening	Resistance band stretch	3 sets, 12 repetitions	Strengthening interscapular muscles to increase spinal stability and improve posture.
Weeks 1–4	Interscapular muscle strengthening	Dumbbell rowing	3 sets, 12 repetitions	Strengthening the middle back and shoulder muscles to improve posture and support the spine.
Weeks 1–4	Balance exercises	Bridge with therapy ball	3 sets, 15 repetitions	Strengthening core muscles and improving balance and body stability.
Weeks 1–4	Balance exercises	Single-leg standing	3 sets, 30 seconds each leg	Enhancing balance and strengthening lower limb and calf muscles.
Weeks 1–4	Breathing exercises	Diaphragmatic breathing	5 minutes	Improving respiratory function and reducing stress and muscular tension.
Weeks 5–8	Interscapular muscle strengthening	Resistance band stretch	3 sets, 12 repetitions	Strengthening interscapular muscles and increasing spinal stability.
Weeks 5–8	Interscapular muscle strengthening	Dumbbell rowing	3 sets, 12 repetitions	Strengthening the middle back and shoulder muscles to provide greater spinal support.
Weeks 5–8	Corrective exercises (abdominal, back, neck)	Crunch	3 sets, 15 repetitions	Strengthening abdominal and back muscles to improve spinal posture and prevent injuries.
Weeks 5–8	Corrective exercises (abdominal, back, neck)	Plank	3 sets, 30 seconds	Strengthening core muscles to enhance body stability and reduce lower back and neck pain.
Weeks 5–8	Corrective exercises (abdominal, back, neck)	Corrective neck exercises	3 sets, 12 repetitions	Strengthening neck muscles to reduce pain and improve muscular function.
Weeks 5–8	Breathing exercises	Diaphragmatic breathing	5 minutes	Improving breathing and reducing muscular tension.
Weeks 9–12	Interscapular muscle strengthening	Resistance band stretch	3 sets, 15 repetitions	Strengthening interscapular muscles and increasing spinal stability.
Weeks 9–12	Interscapular muscle strengthening	Dumbbell rowing	3 sets, 15 repetitions	Strengthening the middle back and shoulder muscles to provide greater spinal support.
Weeks 9–12	Corrective exercises (abdominal, back, neck)	Crunch	3 sets, 20 repetitions	Strengthening abdominal and back muscles to improve spinal posture and prevent injuries.
Weeks 9–12	Corrective exercises (abdominal, back, neck)	Plank	3 sets, 60 seconds	Strengthening core muscles to enhance body stability and reduce lower back and neck pain.
Weeks 9–12	Corrective exercises (abdominal, back, neck)	Corrective neck exercises	3 sets, 15 repetitions	Strengthening neck muscles to reduce pain and improve muscular function.
Weeks 9–12	Lower limb strengthening exercises	Toe standing	3 sets, 15 repetitions	Strengthening calf muscles to improve balance and spinal stability.
Weeks 9–12	Breathing exercises	Diaphragmatic breathing	5 minutes	Improving respiratory function and reducing muscular stress.

Findings and Results

Indicators corresponding to the participants' individual characteristics are presented in Table 2. As shown, individual characteristics including age, height, and weight were examined across the three study groups. The mean, standard deviation, minimum, and maximum values are reported separately in the table. Descriptive statistics for the three main study variables are also presented in the table.

Table 2. Demographic Characteristics and Statistics Related to the Study Variables

Group	Mean Age (years)	Mean Height (cm)	Mean Weight (kg)	Mean Initial and Final Cobb Angle (degrees)	Mean Initial and Final Mobility	Mean Initial and Final Pain
Schroth	13.13	155.89	60.48	14.95 / 12.57	17.08 / 20.20	7.45 / 6.10
Modified Schroth	13.06	156.30	57.89	14.02 / 10.57	16.97 / 20.47	6.68 / 4.94
Control	12.80	157.05	60.23	14.31 / 14.72	17.90 / 17.39	6.48 / 6.26

In Table 3, the summary results of the combined analysis of variance and the adjusted means of the study variables are presented.

Table 3. Results of Multivariate Analysis of Variance for the Study Variables

Variable	Main Effect of Groups (F)	Significance Level (p)	Effect Size (η^2)	Adjusted Mean (Control)	Adjusted Mean (Schroth)	Adjusted Mean (Modified Schroth)
Cobb angle	68.710	0.000	0.770	14.81	12.19	10.86
Mobility	38.117	0.000	0.650	16.92	20.39	20.75
Pain intensity	14.757	0.000	0.419	6.49	5.75	5.06

The results of the multivariate analysis of variance for the research hypotheses indicated that Schroth and modified Schroth exercises had significant effects on Cobb angle, mobility, and pain intensity. For Cobb angle, an F value of 68.710 and $p < 0.001$ indicated significant differences between the intervention groups and the control group, with an effect size of 0.770, reflecting a strong intervention effect. The modified Schroth group showed the greatest reduction in Cobb angle, with an adjusted mean of 10.86. Regarding mobility, an F value of 38.117 and $p < 0.001$ indicated a significant increase in mobility, with an effect size of 0.650. Both Schroth and modified Schroth groups demonstrated similar improvements in mobility, although the modified Schroth group showed slightly greater effectiveness. For pain intensity, an F value of 14.757 and $p < 0.001$ indicated that both exercise programs significantly reduced pain, with an effect size of 0.419. The modified Schroth group exhibited a notably greater reduction in pain compared with the other groups. The results of the statistical analyses comparing Schroth and modified Schroth exercises on Cobb angle, mobility, and pain intensity are presented in Table 4.

Table 4. Results of Statistical Analyses Comparing Schroth and Modified Schroth Exercises on the Study Variables

Variable	Group	Mean	Standard Deviation	F Statistic (Homogeneity of Variance)	Significance Level (p)	t Statistic (Group Comparison)	Degrees of Freedom	Significance Level (p)
Cobb angle	Schroth	12.57	1.34	0.507	0.482	3.545	28	0.001
	Modified Schroth	10.57	1.73					
Mobility	Schroth	20.20	2.25	1.971`	0.171	−0.270	28	0.789
	Modified Schroth	20.47	3.02					
Pain intensity	Schroth	6.10	1.04	0.073	0.788	3.101	28	0.004
	Modified Schroth	4.94	0.98					

The results of the analyses indicated that modified Schroth exercises were more effective than Schroth exercises in reducing the Cobb angle ($t = 3.545$, $p = 0.001$). With respect to mobility, no significant difference was observed between the two groups ($t = -0.270$, $p = 0.789$). However, in reducing pain intensity, the modified Schroth group demonstrated a significantly greater reduction compared with the Schroth group (t = 3.101, p = 0.004). Homogeneity of variance tests for all three variables indicated no violations affecting the group comparisons.

Discussion and Conclusion

The findings of the present study demonstrated that both Schroth and modified Schroth exercise programs produced statistically significant improvements in Cobb angle, spinal mobility, and pain intensity in adolescents with idiopathic scoliosis. These results reinforce the growing body of evidence supporting physiotherapy scoliosis-specific exercises as an effective conservative approach for managing adolescent idiopathic scoliosis and confirm that active, three-dimensional corrective exercise interventions can positively influence both structural and functional outcomes (10, 11). The magnitude of change observed across outcomes indicates that targeted exercise programs may play a clinically meaningful role in slowing curve progression, enhancing movement capacity, and alleviating pain during a critical developmental period.

With respect to Cobb angle, the results showed a significant reduction in spinal curvature in both intervention groups compared with the control group, with the modified Schroth program producing a greater corrective effect. This finding is consistent with previous randomized and controlled trials reporting that Schroth-based interventions can reduce Cobb angle and stabilize spinal deformity in adolescents with idiopathic scoliosis (13-15). The superior effect of the modified Schroth program may be attributed to its broader neuromuscular and biomechanical focus. By integrating additional strengthening exercises for the abdominal, back, neck, and lower-extremity musculature, the modified protocol likely enhanced postural chain integration and load distribution across the spine. Such adaptations may improve active self-correction capacity and spinal alignment during both static and dynamic tasks, thereby facilitating greater reductions in curvature magnitude (20, 23).

Biomechanically, scoliosis is associated with asymmetric muscle activation, altered spinal stiffness, and compromised proprioceptive feedback. Exercise programs that address these impairments through three-dimensional correction and neuromuscular re-education are more likely to yield meaningful structural changes (4, 5). The findings of the present study support this rationale and align with evidence indicating that curve flexibility and neuromuscular control are key determinants of responsiveness to conservative treatment (6). The greater Cobb angle reduction observed in the modified Schroth group suggests that expanding traditional Schroth principles to include global stabilization and functional strengthening may amplify corrective effects beyond those achieved through segment-specific training alone.

Spinal mobility also improved significantly in both intervention groups, whereas no meaningful change was observed in the control group. These results corroborate earlier studies demonstrating that exercise-based rehabilitation can enhance flexibility and range of motion in adolescents with scoliosis (3, 30). The lack of a statistically significant difference between the Schroth and modified Schroth groups for mobility outcomes suggests that the core principles shared by both programs—namely spinal elongation, rotational correction, and controlled movement—are sufficient to elicit functional gains in mobility. Schroth exercises emphasize active lengthening and derotation of the spine, which may directly address restrictions in segmental motion regardless of additional strengthening components (12).

Nevertheless, the slightly higher adjusted mean for mobility in the modified Schroth group may reflect incremental benefits of integrating trunk and lower-extremity stabilization exercises. Improvements in balance and postural control have been linked to enhanced spinal mobility, particularly when corrective exercises are combined with functional training elements (19, 22). These findings suggest that while traditional Schroth exercises are effective for improving movement capacity, modified protocols may offer modest additional advantages in facilitating the transfer of mobility gains into functional postures and daily activities.

Pain intensity decreased significantly in both intervention groups, with the modified Schroth program producing a greater reduction than the traditional Schroth protocol. Although pain is not always a dominant symptom in adolescent idiopathic scoliosis, it represents an important clinical outcome due to its association with reduced physical activity participation and diminished quality of life (2). The present findings align with previous research indicating that scoliosis-specific exercises can alleviate pain through improvements in muscle balance, postural alignment, and neuromuscular control (16, 29). The enhanced analgesic effect observed in the modified Schroth group may be explained by the inclusion of core stabilization and strengthening exercises, which have been shown to reduce pain in various musculoskeletal conditions by improving load sharing and reducing compensatory muscle overactivity (19, 21).

From a neurophysiological perspective, exercise-induced modulation of pain perception may also contribute to these outcomes. Emerging evidence suggests that structured therapeutic exercise can promote neuroplastic changes in central pain processing pathways, leading to improved pain regulation and reduced sensitivity (25, 26). By combining three-dimensional corrective movements with stabilization and functional strengthening, the modified Schroth program may provide a more robust stimulus for sensorimotor integration and central adaptation, thereby enhancing pain reduction. This interpretation is consistent with studies highlighting the role of sensorimotor stabilization and behavioral engagement in achieving sustainable pain relief through exercise-based rehabilitation (24).

The absence of significant changes in the control group across all outcome variables underscores the limited impact of routine daily activities on scoliosis-related impairments during adolescence. This finding reinforces the necessity of structured, targeted exercise interventions to address the multifactorial consequences of idiopathic scoliosis. Moreover, the observed effect sizes for Cobb angle, mobility, and pain suggest that both exercise programs produced clinically relevant improvements, with the modified Schroth protocol demonstrating particular advantages in structural correction and pain management. These results are in agreement with comparative studies reporting superior outcomes when Schroth exercises are combined with additional corrective or stabilization components (20, 28).

Collectively, the findings of this study contribute to the growing evidence base supporting the use of individualized, active exercise programs in the conservative management of adolescent idiopathic scoliosis. They also highlight the potential value of modifying traditional Schroth protocols to address broader neuromuscular and functional demands. Given the heterogeneity of scoliosis presentations and the dynamic nature of adolescent growth, such adaptable and comprehensive approaches may be particularly well suited to optimizing long-term outcomes.

Despite its strengths, the present study has several limitations that should be considered when interpreting the findings. The sample size was relatively small and limited to male adolescents within a specific age range, which may restrict the generalizability of the results to female populations or other age groups. The intervention period, although sufficient to detect short-term changes, did not allow for long-term follow-up to determine the sustainability of the observed improvements. In addition, reliance on radiographic assessment for Cobb angle measurement, while clinically necessary, limited the frequency of structural evaluations due to ethical considerations related to radiation exposure. Finally, potential confounding factors such as growth velocity, physical activity outside the intervention, and psychosocial influences were not fully controlled.

Future studies should consider larger, more diverse samples that include both sexes and a wider range of scoliosis severities. Longitudinal designs with extended follow-up periods are recommended to evaluate the durability of treatment effects and their influence on curve progression during growth. Incorporating non-invasive assessment tools for posture and mobility could enhance outcome monitoring while minimizing radiation exposure. Comparative studies examining different combinations of scoliosis-specific exercises, stabilization training, and functional activities may further clarify optimal program components and dosing strategies.

From a practical perspective, the findings suggest that both Schroth and modified Schroth exercise programs can be effectively implemented in clinical and educational settings for adolescents with idiopathic scoliosis. Practitioners may consider incorporating modified Schroth protocols when the primary goals include enhanced pain reduction and greater structural correction. Emphasis should be placed on individualized exercise prescription, consistent supervision, and integration of corrective postures into daily activities. Collaboration between physical educators, corrective exercise specialists, and physiotherapists may further enhance intervention effectiveness and support long-term adherence.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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References

1. Koumbourlis AC. Scoliosis and the respiratory system. Paediatric Respiratory Reviews. 2006;7(2):152-60. doi: 10.1016/j.prrv.2006.04.009.
2. Tones M, Moss N, Polly Jr DW. A review of quality of life and psychosocial issues in scoliosis. Spine. 2006;31(26):3027-38. doi: 10.1097/01.brs.0000249555.87601.fc.
3. Saraiva BM, Araujo GS, Sperandio EF, Gotfryd AO, Dourado VZ, Vidotto MC. Impact of scoliosis severity on functional capacity in patients with adolescent idiopathic scoliosis. Pediatric Exercise Science. 2018;30(2):243-50. doi: 10.1123/pes.2017-0080.
4. Little JP, Adam CJ. The effect of soft tissue properties on spinal flexibility in scoliosis: biomechanical simulation of fulcrum bending. Spine. 2009;34(2):E76-E82. doi: 10.1097/BRS.0b013e31818ad584.
5. Barrack RL, Whitecloud T, 3rd, Burke SW, Cook SD, Harding AF. Proprioception in idiopathic scoliosis. Spine. 1984;9(7):681-5. doi: 10.1097/00007632-198410000-00005.

6. Yao G, Cheung JP, Shigematsu H, Ohrt-Nissen S, Cheung KM, Luk KD, et al. Characterization and predictive value of segmental curve flexibility in adolescent idiopathic scoliosis patients. Spine. 2017;42(21):1622-8. doi: 10.1097/BRS.0000000000002046.
7. Hong JY, Suh SW, Modi HN, Hur CY, Song HR, Ryu JH. Centroid method: reliable method to determine the coronal curvature of scoliosis: a case control study comparing with the Cobb method. Spine. 2011;36(13):E855-E61. doi: 10.1097/BRS.0b013e3181fde346.
8. Landauer F, Wimmer C, Behensky H. Estimating the final outcome of brace treatment for idiopathic thoracic scoliosis at 6-month follow-up. Pediatric Rehabilitation. 2003;6(3-4):201-7. doi: 10.1080/13638490310001636817.
9. Cheung JP, Chong CH, Cheung PW. Underarm bracing for adolescent idiopathic scoliosis leads to flatback deformity: the role of sagittal spinopelvic parameters. The Bone & Joint Journal. 2019;101(10):1370-8. doi: 10.1302/0301-620X.101B11.BJJ-2019-0515.R1.
10. Berdishevsky H, Lebel VA, Bettany-Saltikov J, Rigo M, Lebel A, Hennes A, et al. Physiotherapy scoliosis-specific exercises-a comprehensive review of seven major schools. Scoliosis and Spinal Disorders. 2016;11:1-52. doi: 10.1186/s13013-016-0076-9.
11. Weiss HR, Turnbull D, Tournavitis N, Borysov M. Treatment of scoliosis-evidence and management (review of the literature). Middle East Journal of Rehabilitation and Health. 2016;3(2). doi: 10.17795/mejrh-35377.
12. Lehnert-Schroth C. Three-dimensional treatment for scoliosis: a physiotherapeutic method for deformities of the spine: Martindale Press; 2007.
13. Kuru T, Yeldan İ, Dereli EE, Özdinçler AR, Dikici F, Çolak İ. The efficacy of three-dimensional Schroth exercises in adolescent idiopathic scoliosis: a randomised controlled clinical trial. Clinical Rehabilitation. 2016;30(2):181-90. doi: 10.1177/0269215515575745.
14. Kim MJ, Park DS. The effect of Schroth's three-dimensional exercises in combination with respiratory muscle exercise on Cobb's angle and pulmonary function in patients with idiopathic scoliosis. Physical Therapy Rehabilitation Science. 2017;6(3):113-9. doi: 10.14474/ptrs.2017.6.3.113.
15. Gao A, Li J, Shao R, Yu M, Wu T, Wang Y, et al. Improvement of health-related quality of life and radiographic parameters in adolescent idiopathic scoliosis patients after Schroth exercises. Research Square. 2020:1-4. doi: 10.21203/rs.3.rs-33670/v1.
16. Burger M, Van Rooyen C, Du Plessis LZ, Geldenhuys L, Myburgh E, Coetzee W, et al. The effectiveness of Schroth exercises in adolescents with idiopathic scoliosis: A systematic review and meta-analysis. South African Journal of Physiotherapy. 2019;75(1):1-9. doi: 10.4102/sajp.v75i1.904.
17. Van Rooyen C, Du Plessis LZ, Geldenhuys L, Myburgh E, Coetzee W, Vermeulen N, et al. The effectiveness of Schroth exercises in adolescents with idiopathic scoliosis: A systematic review and meta-analysis. South African Journal of Physiotherapy. 2019;75(1):1-9. doi: 10.4102/sajp.v75i1.904.
18. Abdelaal AA, Abd El Kafy EM, Elayat MS, Sabbahi M, Badghish MS. Changes in pulmonary function and functional capacity in adolescents with mild idiopathic scoliosis: observational cohort study. Journal of International Medical Research. 2018;46(1):381-91. doi: 10.1177/0300060517715375.
19. Mazloum V, Sahebozamani M. Comparison of two stability training programs and Pilates method on the rehabilitation of patients with non-specific chronic back pain. Daneshvar Medicine. 2014;22(1):59-68.
20. Rrecaj-Malaj S, Beqaj S, Krasniqi V, Qorolli M, Tufekcievski A. Outcome of 24 weeks of combined schroth and pilates exercises on cobb angle, angle of trunk rotation, chest expansion, flexibility and quality of life in adolescents with idiopathic scoliosis. Medical Science Monitor Basic Research. 2020;26. doi: 10.12659/MSMBR.920449.
21. Chughtai MDB, Shabbir H, Basim M, Rubab Ue, Manzoor A, Ali A, et al. Impact of Core Stabilization Exercises Versus Pilates on Pain Intensity, Lumbar Range of Motion, and Daily Activity Performance in Patients With Lumbar Disc Herniation: A Randomized Controlled Trial. JHWCR. 2025:e531. doi: 10.61919/cxj8p995.
22. Gheitasi M, Pasandideh M, Lordgoee M, Samavi M, Alafan N. Effect of eight-weeks pilates exercises on scoliosis deformity and improve balance in female students. Journal of Applied Exercise Physiology. 2017;13(20):61-73.
23. Monticone M, Ambrosini E, Cazzaniga D, Rocca B, Ferrante S. Active self-correction and task-oriented exercises reduce spinal deformity and improve quality of life in subjects with mild adolescent idiopathic scoliosis. Results of a randomised controlled trial. European Spine Journal. 2014;23:1204-14. doi: 10.1007/s00586-014-3241-y.
24. Engel T, Niederer D, Arampatzis A, Banzer W, Beck H, Floessel P, et al. Sensorimotor stabilization exercises with and without behavioural treatment in low back pain: Feasibility and effects of a multicentre randomized controlled trial. Archives of Rehabilitation Research and Clinical Translation. 2025:100430. doi: 10.1016/j.arrct.2025.100430.

25. Zou J, Hao S. Exercise-induced neuroplasticity: A New Perspective on Rehabilitation for Chronic Low Back Pain. Frontiers in Molecular Neuroscience. 2024;17:1407445. doi: 10.3389/fnmol.2024.1407445.

26. Liu JQ, Mak YW, Tang AL, Kwan C, Al Zoubi F, Wong TK, et al. Effects of acceptance and commitment therapy plus exercise for older adults with chronic low back pain: A preliminary cluster randomized controlled trial with qualitative interviews. The Journal of Pain. 2025:105350. doi: 10.1016/j.jpain.2025.105350.

27. Aroeira RM, de Las Casas EB, Pertence AE, Greco M, Tavares JM. Non-invasive methods of computer vision in the posture evaluation of adolescent idiopathic scoliosis. Journal of Bodywork and Movement Therapies. 2016;20(4):832-43. doi: 10.1016/j.jbmt.2016.02.004.

28. ShahrokhI P, Nobakht MR, Nouri AA, Yousefi HR. Comparison of the effects of two training programs of Schroth and modified Schroth on Cobb angle, spinal mobility, and pain in adolescents with idiopathic scoliosis: A randomized controlled trial. Journal of Mazandaran University of Medical Sciences. 2018;28(165):151-60.

29. HwangBo PN. Psychological and physical effects of Schroth and Pilates exercise on female high school students with idiopathic scoliosis. The Journal of Korean Physical Therapy. 2016;28(6):364-8. doi: 10.18857/jkpt.2016.28.6.364.

30. Fusco C, Zaina F, Atanasio S, Romano M, Negrini A, Negrini S. Physical exercises in the treatment of adolescent idiopathic scoliosis: an updated systematic review. Physiotherapy Theory and Practice. 2011;27(1):80-114. doi: 10.3109/09593985.2010.533342.