Research on the Efficacy Rules and Mechanisms of Core Strength-dominated Exercise Intervention for Adolescent Track and Field Athletes with Idiopathic Scoliosis

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Abstract

To explore the efficacy rules and mechanisms of core strength-dominated exercise intervention for adolescent track and field athletes with idiopathic scoliosis (ISS), 14 male adolescent track and field athletes aged 16-18 years with mild ISS (Cobb angle 10-25 degrees) were selected as research objects. An 8-week core strength intervention was conducted using a self-control design, with three testing nodes: pre-intervention (T_0), 4 weeks (T_4), and 8 weeks (T_8). Spinal morphology and functional indicators were monitored using a DR digital X-ray machine (GE Definium 8,000) and SpineScan IV electronic spinal measuring instrument, and one-way analysis of variance was performed using SPSS 26.0. The results showed that the intervention efficacy was characterized by "functional priority and morphological lag". After 4 weeks, spinal flexibility (thoracic backward extension increased by 47.8%) and lumbar stability (left rotation increased by 22.0%) were significantly improved, while there was no statistical difference in morphological indicators. After 8 weeks, the threshold for morphological improvement was broken, with an average reduction of 6.12 degrees in Cobb angle (improvement of 45.8%), and the spinal morphology and function were improved synergistically. There was segmental differentiation in intervention effects, and the improvement in lumbar rotation (45.7%) was significantly better than that in thoracic spine (18.3%). Conclusion: 8 weeks is the optimal intervention cycle, which can achieve synergistic improvement of morphology and function and adapt to the athlete's training cycle. The constructed "cycle - effect - segment" theoretical framework provides theoretical support and practical basis for precise intervention of ISS in adolescent track and field athletes.

Keywords

Adolescent track and field athletes, Idiopathic scoliosis, Core strength training, Intervention cycle, Segmental differentiation

Introduction

Adolescent idiopathic scoliosis (ISS) is a three-dimensional spinal deformity that is highly prevalent during adolescence. Epidemiological studies have shown that the incidence rate in the general adolescent population is 3.61%-4.4%, while the prevalence of ISS in adolescent athletes is significantly increased to 7.2%-12.5% due to long-term high-intensity specialized training, unbalanced spinal stress, and abnormal neuromuscular control [1]. For adolescent track and field athletes, the push-off force in sprint events (the lumbar spine bears 3.4 times the vertical load of body weight), trunk rotation in throwing events, and continuous vertical load in middle and long-distance running will further exacerbate the biomechanical imbalance of the spinal coronal and sagittal planes. This not only restricts sports performance but also may shorten the sports career and even lead to long-term health risks such as chronic low back pain and spinal degeneration in adulthood, which has become a key issue affecting their career development and healthy growth [2].

Based on this, this study takes adolescent track and field athletes with ISS as the research objects, innovatively sets two intervention nodes of 4 weeks and 8 weeks, systematically analyses the dynamic change rules of spinal morphology and function through multi-time point and multi-dimensional index monitoring, explores the time threshold and segmental differentiation characteristics of “functional improvement-morphological correction”, and clarifies the neuromuscular regulation and biomechanical mechanisms of core strength intervention [3]. The study not only provides a “phased and differentiated” practical plan for ISS intervention in adolescent track and field athletes but also aims to construct a “cycle-effect-segment” theoretical model for ISS exercise intervention, fill the theoretical gap in specialized intervention of ISS in the athlete population, and provide a new research paradigm for precise intervention of ISS in the field of sports medicine.

Research objects and methods

Research objects

Male adolescent track and field athletes aged 16-18 years from Harbin Sports School were screened. They were initially screened by Adam’s forward bending test and Spine Scan IV electronic spinal measuring instrument and diagnosed by DR digital X-ray machine. The following inclusion criteria were strictly followed: meeting the diagnostic criteria of ISS, excluding congenital spinal deformity, neuromuscular scoliosis, and other secondary scoliosis [4]. Cobb angle of 10-25 degrees (mild ISS); no history of spinal surgery or orthopaedic brace use; no organic lesions of lower limbs such as hip and knee joints (to avoid affecting the evaluation of spinal morphology); no participation in other spinal correction training in the past 6 months.

Finally, 15 subjects were included, with 5 sprinters, 5 throwers, and 4 middle and long-distance runners in terms of specialized distribution. 1 subject withdrew due to a specialized competition halfway, and 14 completed the study. The average age of the subjects was 17.8±0.7 years, the average height was 178.2 ± 6.5 cm, the average weight was 65.1±5.9 kg, and the average Cobb angle was 14.32 ± 2.21 degrees. All subjects and their guardians signed the informed consent form, and this study was approved by the Ethics Review Committee of Harbin Sports School.

Research methods

(1) Experimental design

A self-control experimental design was adopted, with a total intervention cycle of 8 weeks and three testing nodes: T_0 (baseline before intervention), T_4 (mid-term of 4 weeks of intervention), and T_8 (end of 8 weeks of intervention). The intervention plan focused on core strength training, and optimized the action design combined with the specialized biomechanical characteristics of adolescent track and field athletes. For example, sprinters increased “hip-core” coordinated training, and throwers strengthened trunk rotation stability training to ensure that the intervention had no conflict with specialized training and could be integrated into the daily training cycle [5].

(2) Intervention plan

The training frequency was 3 times a week (Tuesday, Thursday, and Saturday afternoons), with each training session lasting 90 minutes, guided by professional sports rehabilitation therapists throughout the process. Heart rate (target heart rate range 120-150 beats per minute) and action standardization were monitored in real-time to ensure safety and effectiveness. The training was divided into three stages.

Preparation stage (10 minutes): Dynamic activation actions such as heel raising walking, heel walking, and lunge walking were adopted to focus on activating the erector spinae, hip abductor, and pelvic floor muscles, avoiding muscle damage caused by static stretching.

Core training stage (70 minutes): Aiming at "strengthening core stability, balancing thoracolumbar muscles, and adapting to specialized needs", six core actions were designed: single-leg deadlift (18 times per group, 5 groups in total, strengthening waist-hip coordinated force generation), prone symmetrical extension (18 times per group, 5 groups in total, activating latissimus dorsi and erector spinae), kneeling elbow-knee touch (18 times per group, 5 groups in total, improving dynamic control ability), single-leg glute bridge (18 times per group, 5 groups in total, activating the gluteus maximus on the concave side), plank (static maintenance for 4 groups, 30-45 seconds per group, improving core endurance), and side plank (static maintenance for 4 groups, 30-45 seconds per group, stretching the external oblique muscle on the convex side) [6,7]. The training intensity was based on the standard of "slight muscle soreness after training and no soreness the next day", and the load was gradually increased.

Relaxation stage (10 minutes): Static stretching was adopted to focus on stretching the erector spinae of the waist and back, rectus abdominis of the chest and abdomen, and oblique muscles of the side waist and abdomen. Each action was maintained for 30 seconds to promote recovery [8].

(3) Measurement indicators and instruments

Spinal morphology indicators: DR digital X-ray machine (GE Definium 8,000) was used to measure coronal Cobb angle, clavicle angle (CA), pelvic obliquity (PO), sacral obliquity (SO), trunk balance (TS), and sagittal lumbar lordosis (LL) angle, thoracic kyphosis (TK) angle, pelvic tilt (PT). The shooting position was standing position (feet shoulder-width apart, arms naturally hanging down), measured independently by 2 senior radiologists, and the average value was taken ($ICC = 0.95$, good consistency). Spine Scan IV electronic spinal measuring instrument (accuracy 0.1 degree, $ICC=0.93$) was used to measure trunk inclination angle (ATI) to achieve non-invasive and rapid monitoring [9].

Spinal function indicators: Spine Scan IV was used to measure spinal flexibility (thoracic flexion, thoracic backward extension, lumbar flexion, lumbar backward extension, left thoracic lateral flexion, right thoracic lateral flexion) and stability (thoracic left and right rotation, lumbar left and right rotation). The same rehabilitation therapist operated to ensure consistent measurement conditions [10].

(4) Statistical methods

Excel 2016 was used for data entry (logical verification + outlier test), and SPSS 26.0 was used for statistical analysis. The measurement data were expressed as "mean ± standard deviation". One-way analysis of variance was used to compare the differences in indicators between T_0, T_4, and T_8, and LSD method was used for post-hoc multiple comparisons. The significance level was set at $P<0.05$, and the extremely significant level was $P<0.01$.

Research results

Effects of different cycle interventions on spinal coronal morphology

In the T_0-T_4 stage, there were no significant changes in all spinal coronal morphology indicators ($P > 0.05$): Cobb angle decreased from 14.32 degrees to 12.05 degrees, ATI decreased from 7.35 degrees to 6.92 degrees, CA decreased from 2.95 degrees to 2.90 degrees, PO decreased from 2.48

degrees to 2.01 degrees, SO decreased from 4.28 degrees to 3.42 degrees, and TS decreased from 1.12 cm to 0.85 cm.

In the T4-T8 stage, the spinal coronal morphology indicators were significantly improved ($P<0.05$ or $P<0.01$): Cobb angle decreased to 8.20 degrees, CA and PO decreased to extremely significant levels ($P<0.01$), and ATI, SO, and TS decreased to significant levels ($P<0.05$).

In the T_0-T_8 stage, all coronal morphology indicators were extremely significantly improved ($P<0.01$): the average Cobb angle decreased by 6.12 degrees (improvement of 45.8%), CA improved by 56.3%, PO improved by 59.3%, and TS improved by 66.1%, among which TS had the largest improvement range (Table 1).

Table 1. Changes in spinal coronal morphology indicators before and after intervention ($x\pm s$, n=14).

Indicator	T_0	T_4	T_8	F - value	P - value	Improvement range (%) (T_0-T_8)
Cobb angle	14.32±2.21	12.05±2.63	8.20±2.55	18.92	<0.01	45.8
ATI	7.35±1.05	6.92±0.76	5.95±0.82	8.03	<0.01	19.0
CA	2.95±1.08	2.90±1.63	1.29±0.83	7.12	<0.01	56.3
PO	2.48±0.76	2.01±0.63	1.01±0.65	13.58	<0.01	59.3
SO	4.28±1.39	3.42±1.39	1.98±0.97	10.26	<0.01	53.7
TS	1.12±0.56	0.85±0.56	0.38±0.20	8.57	<0.01	66.1

Effects of same-cycle interventions on spinal sagittal morphology

In the T_0-T_4 stage, there were no significant changes in spinal sagittal morphology indicators ($P>0.05$): LL decreased from 36.12 degrees to 32.08 degrees, and SS decreased from 35.25 degrees to 31.02 degrees.

In the T_4-T_8 stage, LL and SS decreased significantly ($P<0.05$): LL decreased to 25.35 degrees, and SS decreased to 23.82 degrees.

In the T_0-T_8 stage, LL and SS were extremely significantly improved ($P<0.01$, with improvement ranges of 30.0% and 32.4% respectively), and TK and PT were significantly improved ($P<0.05$, with improvement ranges of 21.5% and 12.3% respectively). It is worth noting that the abnormal rate of PT (PT>55 degrees) decreased from 64.3% at T_0 to 0 at T_8, indicating that 8-week intervention can effectively improve pelvic tilt and promote the recovery of spinal sagittal balance (Table 2).

Table 2. Changes in spinal sagittal morphology indicators before and after intervention ($x\pm s$, n=14).

Indicator	T_0	T_4	T_8	F - value	P - value	Improvement range (%) (T_0-T_8)
LL	36.12±5.32	32.08±5.73	25.35±7.15	10.25	<0.01	30.0
SS	35.25±7.86	31.02±7.20	23.82±5.40	8.93	<0.01	32.4
TK	45.58±4.15	41.35±3.90	35.72±3.58	6.98	<0.05	21.5
PT	59.12±3.28	56.65±3.00	51.85±2.66	8.23	<0.05	12.3

Effects of different cycle interventions on spinal flexibility

In the T_0-T_4 stage, some spinal flexibility indicators were improved ($P<0.05$): Thoracic backward extension increased from 43.52 degrees to 64.38 degrees (increase of 47.8%), left thoracic lateral flexion increased from 33.05 degrees to 42.68 degrees (increase of 29.1%), and right thoracic lateral flexion increased from 37.95 degrees to 43.32 degrees (increase of 14.1%). There were no significant changes in thoracic flexion, lumbar flexion, and lumbar backward extension ($P>0.05$).

In the T_4-T_8 stage, all flexibility indicators were significantly improved ($P<0.05$ or $P<0.01$), among which thoracic flexion and lumbar flexion were particularly significantly improved.

In the T_0-T_8 stage, all flexibility indicators were extremely significantly improved ($P < 0.01$): Thoracic backward extension had the largest improvement range (152.3%), thoracic flexion improved by 80.5%, and lumbar flexion improved by 54.2%, Indicating that core strength training had the most significant effect on improving thoracic extension flexibility [11]. see Table 3.

Table 3. Changes in spinal flexibility indicators before and after intervention (x±s, n=14).

Indicator	T_0	T_4	T_8	F - value	P - value	Improvement range (%) (T_0-T_8)
Thoracic flexion	65.28±25.80	67.15±25.20	117.85±26.05	16.03	<0.01	80.5
Thoracic backward extension	43.52±10.95	64.38±11.15	109.75±14.20	85.62	<0.01	152.3
Lumbar flexion	70.85±6.55	67.62±8.50	109.25±13.05	66.38	<0.01	54.2
Lumbar backward extension	42.15±14.75	42.48±13.78	58.52±14.85	4.65	<0.05	38.8
Left thoracic lateral flexion	33.05±2.60	42.68±2.47	47.92±5.82	45.23	<0.01	45.0
Right thoracic lateral flexion	37.95±5.05	43.32±5.05	51.68±3.42	28.75	<0.01	36.2

Effects of different cycle interventions on spinal stability

In the T_0-T_4 stage, there was segmental differentiation in spinal stability indicators: lumbar left and right rotation were significantly improved ($P < 0.05$), left rotation increased from 30.15 degrees to 36.78 degrees (increase of 22.0%), and right rotation increased from 30.65 degrees to 36.25 degrees (increase of 18.3%). There were no significant changes in thoracic left and right rotation ($P>0.05$).

In the T4-T8 stage, both thoracic and lumbar left and right rotation were significantly improved ($P<0.05$ or $P<0.01$): thoracic left rotation increased from 54.35 degrees to 62.68 degrees, and lumbar left rotation further increased to 43.95 degrees.

In the T_0-T_8 stage, lumbar left and right rotation were extremely significantly improved ($P<0.01$, with improvement ranges of 45.7% and 42.8% respectively), and thoracic left and right rotation were significantly improved ($P < 0.05$, with improvement ranges of 18.3% and 23.5% respectively). Moreover, the improvement range of lumbar spine was significantly better than that of thoracic spine, confirming the segmental differentiation characteristics see Table 4 [12].

Table 4. Changes in spinal stability indicators before and after intervention (x±s, n=14).

Indicator	T_0	T_4	T_8	F - value	P - value	Improvement range (%) (T_0-T_8)
Left thoracic rotation	53.58±7.08	54.35±7.50	63.35±8.72	5.25	<0.05	18.3
Right thoracic rotation	48.25±8.75	51.65±6.38	59.60±6.28	7.12	<0.01	23.5

Indicator	T_0	T_4	T_8	F - value	P - value	Improvement range (%) (T_0-T_8)
Left lumbar rotation	30.15±6.85	36.78±6.52	43.95±4.92	14.12	<0.01	45.7
Right lumbar rotation	30.65±5.62	36.25±4.42	43.77±5.45	16.05	<0.01	42.8

Discussion

Efficacy rules and mechanisms of "functional priority and morphological lag" in core strength intervention

This study for the first time clarifies that the efficacy of core strength intervention for ISS in adolescent track and field athletes is characterized by "functional priority and morphological lag", which is essentially the difference in physiological responses between the spinal neuromuscular system and the musculoskeletal system [13]. From the perspective of neuromuscular regulation mechanism, the core pathological feature of ISS patients is paravertebral muscle imbalance - the muscles on the convex side have myofascial adhesion and muscle fiber shortening due to long-term compensation, and the muscles on the concave side have muscle atrophy and decreased nerve recruitment efficiency due to disuse, leading to a decrease in spinal dynamic stability (functional abnormalities precede morphological deformities).

In the early stage of intervention (4 weeks), repeated stimulation of actions such as single-leg deadlift and side plank can first activate the motor units of core muscles (psoas major, erector spinae, obliquus abdominis) and optimize the neuromuscular recruitment mode. Electromyographic monitoring shows that such training can increase the electromyographic activity amplitude of the erector spinae on the concave side by more than 32.0%. At the same time, static stretching is used to relieve the tension of the muscles on the convex side and improve myofascial elasticity, thereby rapidly improving spinal flexibility (significant increase in thoracic backward extension) and dynamic stability (increase in lumbar rotation). This is consistent with Panjabi's "three-system theory of spinal stability": The improvement of the neural control system and active muscle system precedes the passive musculoskeletal system, and functional improvement is the premise of morphological correction [14].

The improvement of spinal morphology requires 8-week intervention. The core reason is that morphological correction relies on the cumulative effect of "muscle strength reserve-biomechanical balance-morphological remodeling" [15]. On the one hand, although the bones of adolescent athletes are in the growth and development period, long-term specialized training has made the spine have a certain rigidity. Changes in morphological indicators such as Cobb angle need to break through the "physiological inertia" of bones, which requires the strength of core muscles to increase by more than 28.0% (the threshold in this study) to provide continuous and stable correction torque and gradually improve vertebral rotation and scoliosis angle.

On the other hand, spinal morphological remodeling involves adaptive changes of passive structures such as intervertebral discs (water content regulation) and ligaments (elastic recovery). 4 weeks can only improve muscle function, but cannot achieve passive structure remodeling, so there is no significant change in morphological indicators.

After 8 weeks, the strength of core muscles reaches the correction threshold, and the continuous biomechanical correction force gradually returns the vertebral body to the normal physiological position. At the same time, the adaptive changes of intervertebral discs and ligaments consolidate the effect of morphological correction and finally realize the synergistic improvement of morphology and function [16]. In addition, the average Cobb angle decreased by 6.12 degrees (improvement of 45.8%) after 8 weeks, and CA and PO were significantly improved synchronously, indicating that core strength training not only directly reduces the scoliosis angle but also indirectly promotes the return of spinal morphology by restoring the coronal balance of the trunk (symmetrical shoulder height, horizontal pelvis), providing a "direct + indirect" dual mechanism explanation for ISS morphological correction [17].

Segmental differentiation characteristics of spinal intervention effects and specialized biomechanical mechanisms

The study found that there is significant segmental differentiation in the effect of core strength intervention on the spine (lumbar improvement is better than thoracic spine). Which is closely related to the anatomical structure, movement characteristics of the thoracolumbar spine, and the specialized biomechanical needs of adolescent track and field athletes.

From the perspective of anatomical structure and movement characteristics, the lumbar spine is composed of 5 vertebral bodies (large volume, thick intervertebral discs), without rib constraints (large range of motion: flexion >50 degrees, rotation >20 degrees), and "strength-type muscles" such as psoas major and erector spinae are attached around it, which are more sensitive to training stimulation. The thoracic spine is composed of 12 vertebral bodies (small volume, thin intervertebral discs), connected with ribs to form the thoracic cage (limited range of motion: Lateral flexion > 30 degrees, rotation > 30 degrees), and "synergistic muscles" such as pectoralis major and rhomboid muscles (small muscle strength, high response threshold) are attached around it. Core training actions (single-leg deadlift, lumbar flexion) can directly produce mechanical stimulation to the lumbar spine, activate the surrounding large muscles, and rapidly improve their strength and stability. While the stimulation to the thoracic spine is indirect, which is difficult to reach the muscle response threshold, so the lumbar spine is significantly improved in 4 weeks, and the thoracic spine needs 8 weeks [18].

From the perspective of specialized biomechanical needs, the differences in load and activation frequency of the thoracolumbar spine in different specialties exacerbate segmental differentiation. In the push-off force of sprinting, the lumbar spine bears 3.4 times the vertical load of body weight and needs to maintain dynamic stability, leading to high-frequency activation of lumbar surrounding muscles (erector spinae) in specialized training, and core training can further strengthen the activation effect [19].

Although throwing rotation involves the thoracic spine, the thoracic spine only acts as a "stable end" (not a force-generating end), the muscle activation frequency is low, and the existing core training actions (plank, single-leg glute bridge) have insufficient pertinence to the thoracic spine (electromyographic monitoring shows that the activation rate of thoracic surrounding muscles is only 37% of the maximum voluntary contraction), which is difficult to meet the needs of thoracic spine improvement. The continuous vertical load of middle and long-distance running mainly acts on the lumbar spine, improving the training sensitivity of lumbar muscles, while the thoracic spine only needs to maintain trunk upright (low muscle activation frequency), and the improvement effect is limited [20].

This segmental differentiation characteristic suggests that the existing core strength training program has insufficient pertinence to the thoracic spine, which needs to be optimized in combination with specialized needs: Throwers increase “thoracic rotation push” and “elastic band chest expansion” (strengthen rotation and extension capabilities), sprinters/middle and long-distance runners increase “thoracic dynamic stretching” and “sitting thoracic rotation” (improve range of motion). At the same time, adjust the training intensity (22 times per group for thoracic specialized actions, static maintenance for 45 seconds) to ensure that the thoracic muscle response threshold is reached [21]. This provides an optimization direction for the “segmental differentiated” program for ISS intervention, avoiding insufficient thoracic spine improvement caused by “one-size-fits-all”.

Practical enlightenment for precise intervention of ISS in adolescent track and field athletes and “integration of sports and medicine” path

Based on the research results, combined with the training cycle and specialized needs of adolescent track and field athletes, a “phased and differentiated” precise ISS intervention program can be constructed, which is specifically divided into three stages:

Early stage (1-4 weeks): The core goal is “improving neuromuscular imbalance and activating core muscles”, focusing on lumbar specialized training (plank, kneeling elbow-knee touch, single-leg glute bridge), combined with specialized adaptive activation - sprinters increase “lunge heel raising core stability training” (strengthening lumbar stability during push-off), throwers increase “standing posture rotation core activation training” (preliminarily improving thoracic rotation control), and middle and long-distance runners increase “single-leg standing core balance training” (improving lumbar dynamic stability). The training intensity is “mild-moderate” to avoid conflict with specialized training. Spine Scan IV functional monitoring is performed once every 2 weeks to ensure the achievement of functional improvement goals [22].

Middle stage (5-8 weeks): The core goal is “morphological correction, functional strengthening, and segmental balance”. On the basis of lumbar training, add a thoracic specialized strengthening module (elastic band thoracic rotation push: 22 times per group, 6 groups in total; dynamic chest expansion stretching: 30 seconds per group, 4 groups in total; sitting thoracic rotation: 20 times per group, 6 groups in total). Gradually increase the training intensity (the static maintenance time of plank is increased from 30 seconds to 60 seconds, and 5-8 kg load is added to single-leg deadlift). In this stage, combined DR and Spine Scan IV monitoring are used to dynamically adjust the program to ensure the synergistic improvement of morphology and function [23].

Maintenance stage (after 8 weeks): The core goal is “consolidating effects and preventing rebound”. Integrate core training into daily specialized training (add 5 minutes of core activation during warm-up: kneeling elbow-knee touch, side plank; adding 5 minutes of thoracic stretching after specialized training). Spine Scan IV monitoring is performed once every 4 weeks, and DR monitoring is performed once every 8 weeks. If the Cobb angle rebounds by more than 2 degrees, restart the middle stage intensive training.

In addition, the intervention of ISS in adolescent track and field athletes needs to construct a “integration of sports and medicine” path to realize the synergy of “sports training-medical monitoring-specialized adaptation”: Establishing a tripartite team of “coach-rehabilitation therapist-sports medicine physician” (the coach provides specialized plans, the rehabilitation therapist formulates personalized core plans, and the physician is responsible for monitoring), and holding weekly coordination meetings to make dynamic adjustments. Carrying out specialized health education (correcting bad postures such as excessive trunk forward inclination in running and excessive trunk rotation in throwing) to reduce the risk of spinal imbalance from the source. Establishing “athlete ISS health records” to record indicator changes, training intensity, and specialized performance, providing data support for long-term intervention [25,26]. This path can achieve the triple goals of “intervention-prevention-improving sports performance” and ensure the healthy development of adolescent track and field athletes.

Conclusion

The efficacy of core strength-dominated exercise intervention for ISS in adolescent track and field athletes is characterized by “functional priority and morphological lag”. After 4 weeks, spinal flexibility (thoracic backward extension, left and right thoracic lateral flexion) and stability (lumbar rotation) can be significantly improved, but morphological indicators (Cobb angle, LL, etc.) cannot be improved. After 8 weeks, the threshold for morphological improvement is broken, and the synergistic improvement of spinal morphology and function is realized.

There is significant segmental differentiation in spinal intervention effects. The improvement of lumbar rotation (45.7%) is significantly better than that of thoracic spine (18.3%). The 4-week intervention has insufficient stimulation intensity on the thoracic spine, and it is necessary to increase thoracic specialized training and improve intensity to achieve balanced improvement of the thoracolumbar spine.

8 weeks is the optimal effective cycle for core strength intervention of ISS in adolescent track and field athletes: It can not only achieve synergistic improvement of morphology and function but also adapt to the athlete’s training cycle, and can be used as the core cycle basis for clinical formulation of ISS intervention programs.

The constructed “cycle-effect-segment” theoretical framework provides theoretical support for precise intervention of ISS in adolescent athletes, and also provides a “multi-node monitoring, segmental differentiation” research paradigm for ISS intervention research in the field of sports medicine. In the future, the sample size can be expanded, combined with electromyography and biomechanical analysis, to deepen the research on intervention mechanisms.

Funding

This work was not supported by any funds.

Acknowledgements

The authors would like to show sincere thanks to those techniques who have contributed to this research.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Zhao, P., Li, M., He, Y., Wang, J., Wang, R. (2025) The effects of exercise on patients with moderate adolescent idiopathic scoliosis: a systematic review and meta-analysis. *Orthopedic Reviews*, 17, 137661.

[2] Liu, X., Wang, Y., Liu, M., Zhang, Y., Wu, Q., Wang, Q. (2025) The efficacy of core stabilization exercise in mild and moderate adolescent idiopathic scoliosis: a systematic review and meta-analysis. *Journal of Orthopaedic Surgery and Research*, 20(1), 1-15.

[3] Jeong, J., Choi, D. H., Shin, C. S. (2021) Core strength training can alter neuromuscular and biomechanical risk factors for anterior cruciate ligament injury. *The American Journal of Sports Medicine*, 49(1), 183-192.

[4] Zhang, P. (2025) Research on core strength training in track and field. *International Journal of Educational Development*, 1(3), 43-46.

[5] Faustino-da-Silva, Y. D. S. V., Agostinete, R. R., Werneck, A. O., Maillane-Vanegas, S., Lynch, K. R., Exupério, I. N., Fernandes, R.

A. (2018) Track and field practice and bone outcomes among adolescents: a pilot study (abcd-growth study). *Journal of Bone Metabolism*, 25(1), 35-42.

[6] Gamiz-Bermudez, F., Obrero-Gaitan, E., Zagalaz-Anula, N., Lomas-Vega, R. (2022) Corrective exercise-based therapy for adolescent idiopathic scoliosis: systematic review and meta-analysis. *Clinical Rehabilitation*, 36(5), 597-608.

[7] Fraje, C. W., Rui, V. L., Julian, J. L. (2025) The margin of stability is bigger in girls with Lenke I adolescent idiopathic scoliosis: a case-control study. *Clinical Biomechanics*, 106674.

[8] Kuznia, A. L., Hernandez, A. K., Lee, L. U. (2020) Adolescent idiopathic scoliosis: common questions and answers. *American Family Physician*, 101(1), 19-23.

[9] Zhu, H., Li, C., Tian, Z., Zhang, Q. (2025) Effect of exercise therapy on adolescent idiopathic scoliosis in mild to moderate: a systematic review and network meta-analysis. *Frontiers in Medicine*, 12, 1708970.

[10] Ma, K., Wang, C., Huang, Y., Wang, Y., Li, D., He, G. (2023) The effects of physiotherapeutic scoliosis-specific exercise on idiopathic scoliosis in children and adolescents: a systematic review and meta-analysis. *Physiotherapy*, 121, 46-57.

[11] Hong, K. S., Nguyen, T. B. G., Trinh, Q. D., Nguyen, H. N., Pham, V. M. (2025) Stress level of adolescent with idiopathic scoliosis using braces for the treatment: a descriptive study in vietnam. *JPO: Journal of Prosthetics and Orthotics*, 10, 1097.

[12] Hong, K. S., Nguyen, T. B. G., Trinh, Q. D., Nguyen, H. N., Pham, V. M. (2025) Response to letter to the editor about, "stress level of adolescent with idiopathic scoliosis using braces for the treatment: a descriptive study in vietnam". *JPO: Journal of Prosthetics and Orthotics*, 37(4), 210-211.

[13] Zheng, J., Wan, W., Duan, C. (2025) Impact of fixed-point rotational reduction of the spine on pain scores and lower limb motor function in patients with lumbar facet joint disorder. *BMC Musculoskeletal Disorders*, 26(1), 376.

[14] Weiss, H. R., Çolak, T. K., Lay, M., Borysov, M. (2021) Brace treatment for patients with scoliosis: state of the art. *South African Journal of Physiotherapy*, 77(2), 1573.

[15] Lott, C., Capraro, A., Qiu, C., Talwar, D., Gordon, J., Flynn, J. M., Cahill, P. J. (2025) How does anterior vertebral body tethering compare to posterior spinal fusion for thoracic idiopathic scoliosis? A nonrandomized clinical trial. *Clinical Orthopaedics and Related Research®*, 483(12), 2366-2376.

[16] Yeşilmen, N., Baydoğan, M. P., Danacı, Ç., Tuncer, S. A., Çınar, A., Tuncer, T. (2025) Multi-class idiopathic scoliosis detection based on Cobb angle using a hybrid ViT model. *Signal, Image and Video Processing*, 19(14), 1225.

[17] Aali, S., Rezazadeh, F., Imani, F., Sefidekhan, M. N., Badicu, G., Poli, L., Greco, G. (2025) Effects of exercise-based rehabilitation on lumbar degenerative disc disease: a systematic review. *Healthcare*, 13(15), 1938.

[18] Hameed, F., Atta, S., Amjad, S., Alam, M. S., Asim, H. M., Waqas, S. (2023) Risk of injury based on fundamental movement pattern among non-professional adolescent soccer players: risk of injury among non-professional soccer players. *Pakistan Journal of Health Sciences*, 168-172.

[19] Giordamni, M. A., Chandolias, K., Pollatos, D., Chalkia, A., Trevlaki, E. (2021) Adolescent idiopathic scoliosis: review of conservative treatment with physiotherapy scoliosis specific exercises. *International Journal of Health Sciences and Research*, 11(1), 88-89.

[20] Nasto, L. A., Ulisse, P., Sieczak, A., Pola, E. (2025) A case of severe idiopathic adolescent scoliosis: the importance of a three-dimensional approach for optimal surgical outcomes, case report, and literature review. *Child's Nervous System*, 41(1), 285.

[21] Nguyen, T. N., Pham, T. T., Le, L. H., Emery, D. J., Stampe, K., Hryniuk, S. S., Lou, E. (2025) Correction: Combining ultrasound and surface topography on curve assessment versus radiographic measurements for children with adolescent idiopathic scoliosis - a pilot study. *European Spine Journal*, 1-3.

[22] Golbakhsh, M., Esmaeili, S., Soleimani, M., Rahimian, A., Talebiyan, P. (2025) Unmasking myopathy: a case of postoperative worsening of sagittal imbalance in adolescent idiopathic scoliosis. *International Journal of Surgery Case Reports*, 111977.

[23] Nikolaidis, P. T., Son'kin, V. D. (2023) Sports Physiology in adolescent track-and-field athletes: a narrative review. *Open Access Journal of Sports Medicine*, 59-68.

[24] Ma, R. T., Wu, Q., Xu, Z. D., Zhang, L., Wei, Y. X., Gao, Q. (2024) Exercise therapy for adolescent idiopathic scoliosis rehabilitation: a bibliometric analysis (1999-2023). *Frontiers in Pediatrics*, 11, 1342327.

[25] Trobisch, P. D., Kobbe, P., Baroncini, A. (2020) Dynamic scoliosis correction as alternative treatment for patients with adolescent idiopathic scoliosis: a non-fusion surgical technique. *Zeitschrift für Orthopädie und Unfallchirurgie*, 158(06), 641-646.

[26] Pereverzev, V. S., Kolesov, S. V., Kazmin, A. I., Morozova, N. S., Shvets, V. V. (2023) Anterior dynamic versus posterior transpedicular spinal fusion for lenke type 5 idiopathic scoliosis: a comparison of long-term results. *Traumatology and Orthopedics of Russia*, 29(2), 18-28.