Original Article

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Serum Irisin Dynamics in Response to Proprioceptive and Strengthening Training in Adolescent Inline Skaters

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Abstract:

Objective: This study investigated the effects of an eight-week proprioceptive and strengthening training program on serum irisin dynamics in adolescent inline skaters and explored its potential implications for performance optimization and injury prevention.

Material and Methods: A quasi-experimental pretest–posttest design with a control group was conducted involving 30 adolescent inline skaters (15 males, 15 females; aged 11–15 years). Participants were randomly allocated into an experimental group (n=15), which received the proprioceptive–strengthening intervention three times weekly for eight weeks, and a control group (n=15), which continued their regular training routines. Serum irisin levels were measured pre- and post-intervention. Statistical analyses included paired t-tests for within-group comparisons and independent t-tests for between-group differences, with a significance threshold set at p-value<0.05.

Results: The experimental group showed a significant increase in serum irisin concentration from 1.310±0.15 ng/mL at baseline to 3.349±0.25 ng/mL post-intervention (p-value<0.001), while the control group demonstrated only a modest rise (1.453±0.20 to 1.603±0.22 ng/mL, p-value=0.016). Between-group analysis confirmed a significant difference in post-test irisin levels favoring the experimental group (p-value=0.004).

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Conclusion: The proprioceptive and strengthening training program effectively enhanced circulating irisin levels, indicating positive neuromuscular and metabolic adaptations. These findings suggest that integrating proprioceptive and strengthening exercises into routine training may support performance optimization and injury prevention in adolescent inline skaters.

Keywords: inline skating, irisin, proprioceptive training, sports injury prevention

Introduction

Inline skating is a high-intensity sport that demands a unique combination of balance, agility, strength, and neuromuscular control, which collectively expose athletes, particularly adolescents, to a substantial risk of musculoskeletal injuries during both training and competition. Recent injury profiling studies, such as those conducted in structured training cohorts, have shown that inadequate neuromuscular control and insufficient conditioning are strongly associated with ankle, knee, and lower-limb injuries, underscoring the urgent need for targeted preventive and performance-optimization strategies in youth sports[1–3].

Recent advances in exercise physiology have highlighted the role of irisin, a myokine secreted primarily by skeletal muscle during physical activity, as a biomarker of exercise adaptation. Irisin plays a critical role in regulating energy metabolism, muscle plasticity, neural activation, and tissue recovery. Emerging evidence suggests that elevated irisin levels may correlate with improved motor coordination, endurance capacity, and musculoskeletal resilience[4–6]. However, studies examining serum irisin dynamics in adolescent athletes, particularly in response to integrated proprioceptive–strengthening interventions, remain scarce[7,8].

Proprioceptive and strengthening exercises are well documented for their ability to enhance neuromuscular coordination, postural balance, and joint stability, contributing to both injury prevention and athletic performance optimization across diverse sports disciplines[9–11]. In addition, a systemic "joint-by-joint" approach has been proposed as a more comprehensive theoretical framework for injury prevention compared to isolated strengthening strategies, further justifying the integration of proprioceptive and strengthening modalities in sport-specific training programs.

Given this context, the present study aimed to investigate the effects of an eight-week proprioceptive and strengthening training program on serum irisin concentrations in adolescent inline skaters. We hypothesized that athletes undergoing the integrated program would exhibit significantly greater increases in circulating irisin levels than those continuing their standard training routines. Understanding these biochemical adaptations may inform the development of evidence-based training strategies to optimize performance and reduce injury risk in young inline skating athletes.

Material and Methods

Study design and participants

This was a randomized controlled trial (field-based, pretest–posttest design) with parallel groups (1:1 allocation ratio) designed to examine the effects of an eight-week proprioceptive and strengthening training program on serum irisin concentrations and neuromuscular performance among adolescent inline skaters. The design maintained ecological validity by integrating the intervention within the athletes' regular training setting.

A total of 30 adolescent inline skaters (15 males and 15 females), aged between 11 and 15 years, were recruited through purposive sampling from a registered skating club in Sidoarjo, Indonesia. Participants were eligible if they were active inline skaters within the specified age range, registered as members of the club, able to follow instructions during training, medically cleared for physical activity, and free from structural lower-limb abnormalities. Written informed consent was obtained from parents or legal guardians, as all participants were under 17 years of age. Exclusion criteria included ongoing participation in rehabilitation programs for existing injuries, absence from three consecutive training sessions without valid reasons, voluntary withdrawal, or any illness or injury that prevented participation during the study. All training sessions were conducted at the Delta Sports Arena, Sidoarjo. Blood collection was performed at the Physiotherapy Laboratory, Faculty of Health Sciences, Universitas Muhammadiyah Sidoarjo, while biochemical analyses were carried out at the Institute of Tropical Disease, Universitas Airlangga.

All procedures involving human participants were reviewed and approved by the Health Research Ethics Committee, Faculty of Medicine, Universitas Airlangga, Surabaya, Indonesia, and were deemed ethically exempt on October 21, 2024 (Ethics Approval No: 145/EC/KEPK/FKUA/2024). The study adhered to the principles of the Declaration of Helsinki. Prior to data collection, all participants and their guardians received a comprehensive explanation of the study objectives, potential risks, and procedures, and written informed consent was obtained from the guardians.

Intervention

Participants in the experimental group completed an eight-week neuromuscular training program, performed three sessions per week on non-consecutive days. Each session lasted approximately 60 minutes, consisting of a 5-minute warm-up, a 40–45-minute main exercise session, and a 5-minute cool-down. All sessions were conducted under the supervision of a licensed physiotherapist and a professional inline skating coach to ensure proper execution, progressive overload, and participant safety.

The proprioceptive–strengthening training program was designed to progress through four phases: static, dynamic, plyometric, and combination, with progressive difficulty every two weeks. Exercises were performed in 3 sets per activity, with 10-second holds, 10 repetitions, or 15 repetitions depending on the exercise. Rest intervals ranged from 30 seconds to 1 minute between sets to maintain training intensity and safety.

Phase 1–2 (Weeks 1–2): Static Phase: Static proprioceptive drills focusing on single-leg stance with eyes open and closed; single-leg stance holding a rubber ball for upper-limb engagement and stability and bilateral stance on a balance board to develop postural control. Phase 3–4 (Weeks 3–4): Dynamic Phase: Side-to-side stepping on a balance board; forward–backward lunges on a BOSU ball; single-leg stance while performing throw-and-catch drills with a rubber ball and ball movement exercises while standing on a balance board to integrate upper-limb coordination.

Phase 5–6 (Weeks 5–6): Plyometric Phase: Two-leg jumps and single-leg jumps for explosive power and ankle stabilization; 20-meter sprints with 10-second rest intervals to train anaerobic capacity and agility and single-leg deadlifts on a foam pad for eccentric strength and proprioceptive control. Phase 7–8 (Weeks 7–8): Combination Phase: Squats with eyes closed for advanced balance and proprioceptive challenge; lunges holding a rubber ball to combine strength and dynamic balance; calf raises on a wobble board for ankle proprioception and strength and interval sprints with directional changes over 20 meters for sport-specific agility and power.

The control group continued with their usual inline skating training routines, consisting mainly of endurance-based exercises such as steady-state running and static stretching, without exposure to the structured neuromuscular intervention.

Outcome measures

Primary outcome: Serum irisin concentration (ng/mL), measured pre- and post-intervention using the Elabscience® Human Irisin ELISA Kit (sensitivity: 9.38 pg/mL; detection range: 15.63–1000 pg/mL).

Sample size calculation

The required sample size was calculated a priori using the formula for comparing two independent means (continuous data), as recommended by Lemeshow et al., Steel and Torrie, and Higgins and Kleinbaum[12]. Using a population standard deviation (σ) of 4.32, a significance level ($Z\alpha/2$) of 1.96, a statistical power ($Z\beta$) of 0.84, and an expected mean difference ($\mu_1-\mu_2$) of 5, a minimum of 12 participants per group was obtained. To account for potential attrition, 15 participants per group were recruited.

Randomization and blinding

Participants were assigned to the experimental or control group using a computer-generated random sequence. Allocation was concealed using sealed opaque envelopes prepared by an independent researcher. Due to the nature of the intervention, blinding of participants and coaches was not feasible. However, laboratory personnel analyzing serum samples were blinded to group assignments.

Blood sampling and laboratory procedures

Venous blood samples (3–5 mL) were collected by qualified medical personnel within 30 minutes after the final training session, centrifuged, aliquoted, and stored at −80 °C until analysis. Serum irisin concentrations were determined using the Human Irisin ELISA Kit (Catalog No. E-EL-H2555; sensitivity: 9.38 pg/mL; Elabscience, Houston, TX, USA) according to the manufacturer's protocol[13].

Statistical analysis

Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 27.0 (IBM Corp., Armonk, NY, USA)[14]. Data normality was tested using the Shapiro-Wilk test, and variance homogeneity was assessed with Levene's test. Within-group comparisons (pre- vs. post-intervention) were analyzed using paired t-tests for parametric data or Wilcoxon signed-rank tests for non-parametric data. Between-group comparisons were analyzed using independent t-tests for parametric data or Mann–Whitney U tests for non-parametric data. A two-tailed $p\text{-value} \leq 0.05$ was considered statistically significant. Power analysis confirmed that the sample size was sufficient to detect the hypothesized effects.

Results

A total of 30 adolescent inline skaters (15 males and 15 females) completed the study without adverse events. All participants demonstrated high adherence to the training sessions, with an attendance rate exceeding 90%. Baseline characteristics, including age, sex distribution, and training experience, were comparable between the experimental and control groups ($p\text{-value}>0.05$), indicating well-matched cohorts. The results of the eight-week proprioceptive–strengthening training program are summarized in Tables 1–3, highlighting changes in serum irisin concentrations.

Table 1 summarizes the baseline demographic and training characteristics of the participants in both groups. A total of 30 adolescent inline skaters were enrolled, evenly distributed between females (50.0%) and males (50.0%). The mean age was comparable between the control group (13.1±1.2 years) and the experimental group (13.3±1.4 years). Anthropometric measures, including height, weight, and body mass index (BMI), showed no significant differences between groups ($p\text{-value}>0.05$), indicating homogeneity in physical profiles. Additionally, participants in both groups reported a similar training experience, averaging approximately 2.7±0.9 years, minimizing variability related to prior skating exposure while ensuring a balanced comparison of intervention effects.

Serum irisin concentrations are summarized in Tables 2 and 3. At baseline, the mean serum irisin levels were similar between groups (1.310±0.15 ng/mL in the experimental group vs. 1.453±0.20 ng/mL in the control group). After eight weeks, the experimental group demonstrated a significant increase to 3.349±0.25 ng/mL (p-value<0.001), representing an approximate 2.6-fold rise. In contrast, the control group showed only a modest increase to 1.603±0.22 ng/mL (p-value=0.016).

Between-group analysis confirmed that post-intervention irisin levels were significantly higher in the experimental group compared with the control group (3.349±0.25 vs. 1.603±0.22 ng/mL, p-value=0.004), with a mean difference of 1.746 ng/mL (95% CI: 1.121–2.371) (Table 3).

Table 3 presents the post-intervention comparison of serum irisin levels between the experimental and control groups after eight weeks of training. The experimental group

Table 1 Baseline characteristics of participants in the control and experimental groups

Characteristics	Control group (n=15)	Experimental group (n=15)	Total (n=30)
Sex			
Female, n (%)	7 (46.7%)	8 (53.3%)	15 (50.0%)
Male, n (%)	8 (53.3%)	7 (46.7%)	15 (50.0%)
Age (years), mean±S.D.	13.1±1.2	13.3±1.4	13.2±1.3
Height (cm), mean±S.D.	154.6±5.9	155.8±6.1	155.2±6.0
Weight (kg), mean±S.D.	47.2±4.8	48.0±5.2	47.6±5.0
BMI (kg/m^2), mean±S.D.	19.7±1.4	19.8±1.5	19.7±1.4
Training experience (years), mean±S.D.	2.6±0.9	2.8±1.0	2.7±0.9

BMI=body mass index, S.D.=standard deviation

Table 2 Descriptive statistics of serum irisin concentrations (ng/mL) in the experimental and control groups

Group	Pre-test (Mean±S.D.)	Post-test (Mean±S.D.)	Mean difference	p-value (within-group)
Experimental (n=15)	1.310±0.15	3.349±0.25	+2.039	<0.001*
Control (n=15)	1.453±0.20	1.603±0.22	+0.150	0.016*

*Paired t-test; *p-value<0.05 indicates statistical significance

Table 3 Between-group comparison of post-test serum irisin concentrations

Group	Post-test serum irisin (ng/mL)	Mean difference (ng/mL)	95% CI	p-value
Experimental (n=15)	3.349±0.25	1.746	1.121-2.371	0.004*
Control (n=15)	1.603±0.22	–	–	–

*Independent t-test; *p-value<0.05 indicates statistical significance, 95% CI=95% confidence interval demonstrated significantly higher serum irisin concentrations than the control group, confirming the effectiveness of the proprioceptive–strengthening program in enhancing circulating irisin levels.

These findings support the hypothesis that neuromuscular-focused training elicits greater physiological adaptations, potentially contributing to improved energy metabolism, muscle function, and performance optimization in adolescent inline skaters.

Discussion

Interpretation of findings

The present study demonstrated a robust increase in serum irisin levels among adolescent inline skaters after participating in an eight-week proprioceptive strengthening training program. The experimental group exhibited a notable rise from 1.310±0.15 ng/mL at baseline to 3.349±0.25 ng/mL at post-test (p-value<0.001), a far greater change compared to the modest increase observed in the control group (1.453±0.20 → 1.603±0.22 ng/mL, p-value=0.016).

This elevation aligns with the established role of irisin as a myokine produced by skeletal muscle in response to contraction, with evidence supporting its involvement in metabolic regulation and muscle adaptation mechanisms[13,15]. Moreover, similar training regimens focusing on resistance or strength training have been linked to increased circulating irisin, particularly when programs are progressive and demand higher intensity[16,17].

Comparison with the existing literature

Evidence regarding chronic exercise effects on irisin is mixed. A systematic review and meta-analysis by Menezes-Junior et al. and Faramarzi et al., observed a non-significant trend toward increased irisin following chronic resistance training, which became significant in subgroups like older adults and high-intensity, progressive training protocols[18,19]. Ji et al. demonstrated that 12-week resistance training in older men led to a significant increase in serum irisin, with larger increases inversely associated with body fat percentage[20,21].

Animal studies also support this trend: eight weeks of swimming resulted in elevated PGC-1α and FNDC5 expression in skeletal muscle and serum irisin levels[22]. Conversely, some human trials found no changes or even reductions in irisin following chronic interventions, possibly due to differences in assay methodologies or exercise modalities[23,24].

Acute effects appear more consistent: irisin typically surges immediately following high-intensity or strenuous bouts of exercise, though concentrations may normalize within an hour in many cases[25]. Our findings suggest that repeated, progressive training over eight weeks likely led to a cumulative elevation in baseline serum irisin levels.

Implications for injury prevention and performance

Although neuromuscular parameters were not directly measured in this study, previous evidence shows that structured training interventions such as plyometric and proprioceptive programs can enhance neuromuscular performance in young athletes[21,24]. The substantial rise in irisin observed here suggests enhanced muscle endocrine cross-talk and potentially improved metabolic functioning, which may contribute to musculoskeletal resilience.

However, these implications should be interpreted with caution. Without direct data on performance or injury outcomes, the current findings only suggest potential associations between elevated irisin and improved adaptation, rather than demonstrating causal effects.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the measurement method relied on ELISA kits, which have been criticized for potential cross-reactivity and the absence of validation against more precise techniques, such as mass spectrometry. This methodological limitation may affect the accuracy of absolute irisin quantification and should be addressed in future research.

Second, the generalizability of the findings is limited because the sample included only adolescent inline skaters. Therefore, the results may not apply to other age groups, performance levels, or sporting populations. Future studies should involve athletes from different disciplines with similar lower-limb demands and include additional biomarkers, such as NAD+ and Creatine Ratio. It is also recommended to perform repeated sampling at both the acute and chronic phases, together with complementary biomarkers, such as BDNF, myostatin, and inflammatory mediators

Third, biomarker dynamics were measured at only two time points, before and after the eight-week intervention. This limited frequency may have missed short-term changes in irisin that occur right after training sessions. Future studies should include control groups and use longer, progressive interventions to provide stronger evidence

Fourth, although the study design was a randomized controlled trial, inconsistencies in reporting (initially described as quasi-experimental) may have caused confusion. This methodological contradiction, along with the omission of secondary outcome data (neuromuscular parameters), represents significant limitations that should be acknowledged.

Fifth, the study did not include objective neuromuscular assessments such as EMG, balance testing, or functional performance evaluations. Future studies should integrate these measures to provide a more complete understanding of neuromuscular adaptations.

Finally, while the study demonstrated significant increases in circulating irisin, it did not investigate downstream mechanistic pathways. Future research should explore the biological processes linking elevated irisin to muscle signaling, adipose tissue browning, and improvements in neuromuscular function and control.

Future directions

Building upon these findings, several recommendations can be made for future studies: First, future investigations should employ more robust analytical techniques, such as liquid chromatography–mass spectrometry, to ensure greater accuracy and reproducibility of irisin measurements. Second, incorporating time-resolved sampling protocols, such as collecting blood samples immediately after training sessions and during recovery, would provide deeper insights into the acute and chronic dynamics of irisin responses. Third, expanding the scope of the research to include diverse populations (e.g., athletes from different sports, older adults, or individuals with metabolic or neuromuscular conditions) would enhance the external validity of these findings. Lastly, integrating modern biomechanical assessments, including wearable sensors and artificial intelligence-based motion analysis, could provide objective insights into movement quality and injury risk. Future studies should aim to correlate biochemical markers such as irisin with biomechanical outcomes to better understand their role in injury prevention and performance optimization[26,27].

Conclusion

The eight-week proprioceptive-strengthening training program significantly increased serum irisin levels in adolescent inline skaters compared with regular training alone. These findings suggest that integrated neuromuscular training enhances metabolic and neuromuscular adaptations, potentially contributing to improved metabolic and muscular adaptation, with possible implications for injury prevention and performance optimization in this athletic population.

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