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Short Foot Exercises as a Preventive Strategy for ACL Injury in Women with Dynamic Knee Valgus

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Abstract

Background: Dynamic knee valgus (DKV) is a well-established contributor to knee injuries, with women at higher risk. Traditional rehabilitation often emphasizes proximal muscle strengthening, but growing research suggests that foot and ankle dysfunction may play a critical role in DKV development. This study aimed to investigate the effects of a 6-week short foot exercise (SFE) program on the DKV angle, navicular drop, ankle dorsiflexion range of motion (DFROM), and proprioceptive acuity at the knee and ankle in women with DKV.

Methods: This quasi-experimental study involved 28 female university students (aged 20-30 years) with DKV and excessive navicular drop, assigned to either an SFE group or a control group. The intervention group performed supervised SFE sessions 3 times per week for 6 weeks. Measurements taken before and after the intervention included DKV angle, navicular drop, ankle DFROM, and proprioceptive acuity at the knee and ankle. Appropriate parametric and nonparametric statistical tests (t-tests, analysis of covariance, Mann–Whitney U, and Wilcoxon test) were used based on data distribution.

Results: After the intervention, the SFE group demonstrated significant improvements compared to the control group in DKV angle (adjusted mean difference = –4.0°, 95% CI: –6.0° to –2.1°, p = 0.001, d = 2.04), navicular drop (–4.2 mm, 95% CI: –5.4 to –2.9 mm, P<0.001, d=2.08), and ankle DFROM (+6.9°, 95% CI: 5.2° to 8.7°, P<0.001, d=2.89). Knee joint proprioception error decreased by –1.2° (95% CI: –1.8° to –0.7°, P<0.001, d=1.47), and ankle proprioception error (dorsiflexion) improved by –1.4° (95% CI: –2.5° to –0.6°, P=0.002, r=0.60). The control group showed no significant changes in any outcome (all P>0.05).

Conclusion: A structured 6-week SFE program effectively enhances foot posture, ankle mobility, and proprioceptive control, leading to reduced knee valgus in young women. These findings support the inclusion of distal kinetic chain exercises in rehabilitation programs aimed at correcting lower limb dysfunction and preventing knee injuries.

Keywords: Dynamic Knee Valgus, Anterior cruciate ligament, Short foot exercises

Conflicts of Interest: None declared
Funding: University of Tehran

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Introduction

Dynamic knee valgus (DKV), characterized by excessive hip adduction and internal rotation, is a significant risk factor for acute and chronic knee conditions, including noncontact anterior cruciate ligament (ACL) injuries and patellofemoral pain syndrome (PFP) (1). Persistent DKV also accelerates joint degeneration, highlighting its long-term clinical impact. Epidemiologically, DKV-related injuries are substantial, with over 250,000 annual ACL ruptures in the United States, 70% of which are noncontact (2). Females face a 4 to 6 times higher ACL injury risk than males (3), leading to healthcare costs surpassing $650 million yearly (2, 3). Additionally, 50% to 100% of women with ACL injuries develop knee osteoarthritis within 12 to 20 years (4), while PFP, affecting 15% to 45% of active individuals, is strongly linked to DKV (5). These statistics highlight the importance of understanding and addressing

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↑***What is "already known" in this topic:***
Dynamic knee valgus is a known risk factor for ACL injuries, and proximal muscle strengthening has traditionally been emphasized in rehabilitation protocols.

→***What this article adds:***
This study shows that short foot exercises significantly improve knee alignment, foot posture, ankle mobility, and proprioception, highlighting the importance of distal kinetic chain training in ACL injury prevention.

the biomechanical contributors to DKV, particularly in high-risk populations such as young adult females (6).

While traditional interventions for DKV have targeted proximal factors, such as Q-angle correction and quadriceps-hamstring imbalances, their success in mitigating DKV and injury risk has been variable (7). Emerging research highlights neuromuscular control deficits, proprioceptive impairments, and weakness in proximal stabilizers (eg, hip abductors and trunk muscles) as key contributors, particularly in females (8, 9). However, recent attention has turned to distal biomechanical factors, which may initiate or perpetuate valgus collapse (10). Restricted ankle dorsiflexion range of motion (DFROM) is linked to compensatory subtalar pronation and internal tibial rotation, worsening valgus collapse, and increasing patellofemoral stress (11, 12). Additionally, poor foot posture and a weakened medial longitudinal arch impair proprioception and postural stability, further compromising dynamic joint control (13).

These distal dysfunctions may not only contribute directly to abnormal knee kinematics but also diminish the effectiveness of proximal-focused rehabilitation (10). Given these interconnected biomechanical factors, interventions focusing on intrinsic foot muscles, such as the short foot exercise (SFE), have emerged as a promising approach to improving lower limb alignment. Initially developed by Janda, the SFE strengthens plantar sensory feedback, enhancing stability during weight-bearing activities (14). Research shows that activating intrinsic foot muscles (eg, abductor hallucis) via SFE increases arch height, improves ankle proprioception, and enhances overall postural control (15).

By improving sensory input and muscular support at the foot, SFE may generate a bottom-up corrective effect, influencing tibial alignment, knee tracking, and sensorimotor control throughout the kinetic chain (10, 14). This theoretical framework supports a biomechanical rationale for SFE as a means of reducing DKV and enhancing proprioceptive function at more proximal joints (6).

Although the SFE has been well-researched in patients with pes planus (flat feet) (15, 16), its broader effects on lower-limb biomechanics, including DKV, limited ankle DFROM, and proprioceptive deficits, remain understudied (6). To date, no study has systematically evaluated the simultaneous effects of SFE on these interconnected parameters in individuals with symptomatic DKV. Moreover, the interaction between foot posture correction and joint position sense at both the knee and ankle remains largely unexplored.

Given the elevated injury risk among young adult females, this study primarily aimed to investigate whether a 6-week SFE intervention could reduce the DKV angle, while also assessing its secondary effects on navicular drop, ankle DFROM, and proprioceptive accuracy at both the knee and ankle in women aged 20 to 30 years.

By clarifying these effects, this study may contribute to the development of more comprehensive, distal-to-proximal strategies for the prevention of knee injuries in physically active populations.

Methods

Study Design

This study employed a quasi-experimental, nonrandomized pretest-posttest control group design to investigate the effects of SFE on lower limb biomechanics. Participants were allocated to intervention and control groups using matched assignment based on navicular drop and DKV angle; however, no randomization or blinding procedures were applied. Randomization was not implemented due to logistical constraints within the dormitory-based sampling framework and the need to deliver group-based interventions. Instead, matched assignment was employed to control for key baseline characteristics. While this limits internal validity compared to randomized designs, the approach helped to reduce between-group variability and partially mitigate selection bias.

Participants and Sampling

Female university students aged 20 to 30 years, residing in the dormitories of the University of Tehran, were recruited through purposive sampling. Recruitment flyers were distributed in dormitories, and announcements were made via student networks to invite volunteers. Interested individuals underwent a brief screening process to determine eligibility, which included a clinical assessment for DKV and excessive navicular drop based on predefined criteria. A priori power analysis was conducted using G*Power software (Version 3.1.9.2), specifying an effect size of 0.7 (Cohen's d), $\alpha = 0.05$, and statistical power of 95%. The analysis indicated a minimum required sample size of 28 participants (14 per group) for detecting significant between-group differences. To account for potential attrition, 30 participants were initially enrolled (15 per group). After exclusions, the final analysis included 14 participants per group (17).

Ethical Considerations

Ethical approval was granted by the Ethics Committee of the Faculty of Physical Education and Sport Sciences, University of Tehran (Approval Code: IR.UT.SPORT.REC.1402.036), in accordance with the Declaration of Helsinki (18). All participants provided written informed consent after being briefed on the study's purpose, procedures, risks, and their right to withdraw at any time. Confidentiality was maintained throughout. Although ethical standards were upheld, the study did not follow established reporting guidelines such as CONSORT or STROBE, which are recommended for improving transparency and reproducibility in future research.

Inclusion and Exclusion Criteria

Inclusion criteria were as follows: (1) female university students aged 20 to 30 years; (2) with normal body mass index (BMI) (18.5-24.9 kg/m²); (3) no history of lower limb pain, musculoskeletal surgery, or neuromuscular disorders; (4) mild foot pronation (navicular drop 10-11 mm); (5) observable DKV during single-leg squats confirmed by 2D video analysis; and (6) immediate improvement in at least 3 out of 5 squats using a 5 cm heel lift, indicating a foot-related mechanism.

The exclusion criteria were as follows: (1) missing >3 training sessions; (2) developing pain or injury during the intervention; (3) voluntary withdrawal; (4) current use of medications affecting balance or motor control; (5) participation in concurrent rehabilitation or structured training programs; and (6) failure to complete either the pre- or postintervention assessment.

Potential Confounding Factors

To minimize confounding variables, participants were matched for baseline navicular drop and DKV angle. However, possible confounders—such as individual variations in physical activity levels, lower limb dominance, menstrual cycle phase, proprioceptive ability, and habitual footwear—use were not controlled or adjusted statistically. These factors may have influenced the intervention outcomes and should be considered in the interpretation of the results.

Outcome Measures

Primary Outcome

Dynamic Knee Valgus Assessment: DKV was assessed using the double-leg squat (DLS) test at a controlled cadence (80 bpm), standardized to approximately 80° of knee flexion using tactile cues. Each repetition followed a 2-beat descent, 2-beat ascent, and 1-beat pause, with a 1-minute rest between sets. Participants performed 5 squats under 2 conditions: (1) flat heels and (2) 5 cm heel wedges. Photographic analysis was used to evaluate frontal plane knee alignment, with correction defined as ≥3 improved repetitions out of 5. This test demonstrates acceptable inter-rater reliability (intraclass correlation coefficient [ICC], 0.76) and has been validated in similar populations for identifying faulty movement patterns associated with knee injury risk (19) (Figure 1).

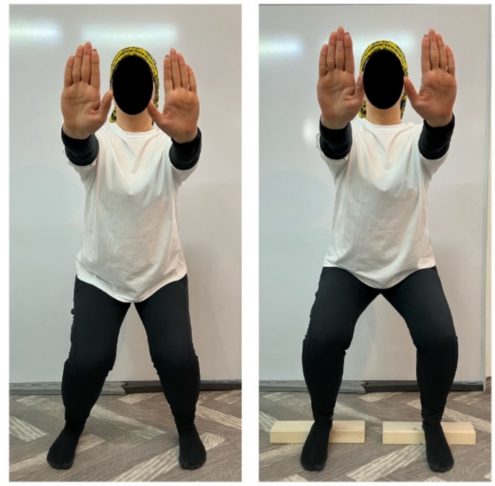

Figure 1. Dynamic Knee Valgus Assessment Method

Secondary Outcomes

Medial Longitudinal Arch Evaluation: The Brody method was used to assess navicular drop. Participants sat with hips and knees flexed at 90°, maintaining a neutral subtalar joint. Navicular height was measured in both seated (non-weight-bearing) and standing (weight-bearing) conditions, and the difference was recorded (16). The average of 3 measurements per limb was used, with high test-retest reliability reported for young adults (ICC, 0.89 dominant, 0.82 nondominant). The Brody test has also shown good validity as a clinical indicator of foot posture and dynamic arch function (20) (Figure 2).

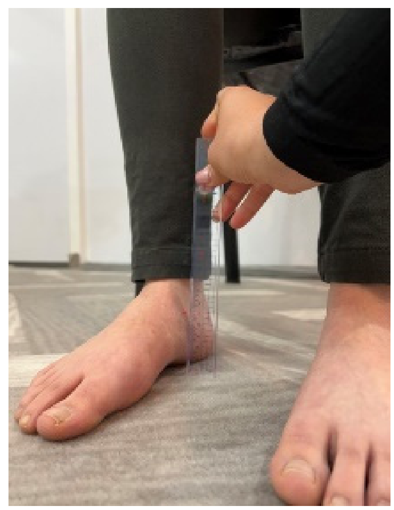

Figure 2. Navicular Drop Assessment Method

Ankle Dorsiflexion Range of Motion (DFROM): Passive ankle dorsiflexion with the knee fully extended was assessed using a standard goniometer while the participant was seated with the foot unsupported. The goniometer was aligned with the lateral malleolus, fibular shaft, and fifth metatarsal. The subtalar joint was held in neutral, and dorsiflexion was performed passively until firm end-range resistance. The mean of 5 trials was recorded. This method has shown high reliability (ICC, 0.90; SEM, 1.8°) in healthy adult populations, including in sports and rehabilitation contexts (11).

Knee Joint Proprioception: Knee proprioception was evaluated using an active joint position reproduction (JPR) test. Participants were seated with 85° of knee flexion and 30° trunk recline. After 2 to 3 familiarization trials with visual feedback, they actively reproduced a 60° knee angle while blindfolded. Absolute angular error (difference from the target angle) was calculated. This method has high validity and excellent intra-session reliability in young adults (ICC, 0.866-0.982; SEM, 0.31°-0.63°), making it suitable for detecting subtle neuromuscular deficits (21).

Ankle Joint Proprioception Assessment: Ankle JPR was conducted in a seated position with eyes closed. The ankle was passively moved to 10° dorsiflexion and returned to neutral, after which participants attempted to replicate the target angle. Absolute error was measured using a goniometer. This method has excellent intersession reliability for joint position reproduction (ICC, 0.79-0.95) and moderate

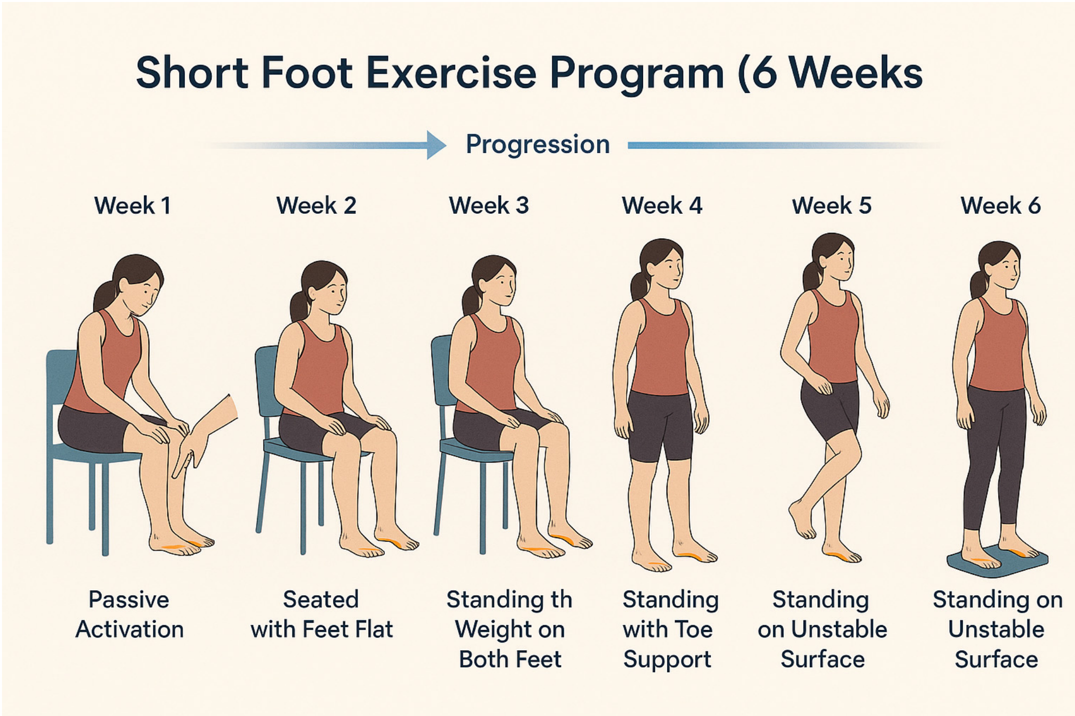

Figure 3. Overview of the six-week training protocol, including progressive short foot exercises performed in sitting and standing positions with increasing difficulty each week.

to good reliability for torque reproduction (ICC, 0.72), and is commonly used in both clinical and athletic settings (22, 23).

Training Protocol: Participants engaged in a 6-week, standardized, and supervised neuromuscular training program comprising 3 weekly sessions, each lasting approximately 35 minutes. Sessions began with a 5-minute warm-up involving dynamic and static stretches, followed by ankle mobilization drills, including (1) slow active dorsiflexion and plantarflexion in a supine position with hips and knees at 90°, (2) therapist-assisted manual mobilization, and (3) TheraBand-assisted mobilization for progressive resistance. A certified exercise specialist supervised all sessions to ensure correct technique and adherence to progression (24).

The core of the intervention consisted of progressively structured SFE advancing weekly in difficulty. The sequence included: Week 1 (passive SFE with manual feedback), Week 2 (seated active SFE), Week 3 (seated with resistance), Week 4 (bilateral standing), Week 5 (single-leg stance with toe support), and Week 6 (single-leg on unstable surface). Participants performed 3 sets of 12 repetitions, each with a 5-second isometric hold, and 2-minute rest intervals between sets. Exercises were performed in both seated and standing positions to promote comprehensive neuromuscular adaptation (16, 24) (Figure 3).

Statistical Analysis

Data analysis was performed using SPSS Version 23. The Shapiro–Wilk test was used to assess data normality. Paired t-tests or Wilcoxon signed-rank tests were applied for within-group comparisons. In contrast, ANCOVA or Mann-Whitney U tests were used for between-group analyses, depending on data distribution. Statistical significance was set at $P < 0.05$.

Results

Descriptive statistics for participants' age, height, weight, and BMI at baseline are presented in Table 1. Independent t-tests revealed no significant differences between the control and exercise groups for any of the demographic variables ($P > 0.05$), indicating that the 2 groups were comparable at the start of the study. No covariates showed significant baseline imbalance; however, subsequent analyses controlled for pretest scores to account for potential confounders.

Table 1. Baseline Demographic Characteristics of Participants

Characteristic	Control Group (n = 14)	Exercise Group (n = 14)	p-value	95% CI of Difference	Cohen's d
Age (years)	23.64 ± 2.24	23.85 ± 3.52	0.860	–2.02 to 1.60	0.07
Height (m)	1.67 ± 0.01	1.69 ± 0.02	0.090	–0.04 to 0.004	0.78
Weight (kg)	60.78 ± 1.88	62.21 ± 3.37	0.170	–3.50 to 0.67	0.52
BMI (kg/m²)	21.57 ± 0.56	21.73 ± 1.23	0.650	–0.56 to 0.87	0.16

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Normality Assessment

Shapiro-Wilk tests confirmed normal distribution for all outcome variables ($P > 0.05$), except ankle proprioception in the dorsiflexion position ($P < 0.01$). Accordingly, parametric tests (paired t-tests and ANCOVA controlling for baseline values) were used for normally distributed variables. In contrast, nonparametric tests (Mann-Whitney U and Wilcoxon signed-rank test) were used for ankle proprioception.

Dynamic Knee Valgus Angle

ANCOVA, controlling for baseline values, indicated a significant reduction in the dynamic knee valgus angle in the exercise group compared to the control group at post-test ($F(1, 26) = 13.90$, $P = 0.001$, $\eta^2 = 0.35$, 95% CI for adjusted mean difference: –6.0° to –2.1°; see Table 2). A significant within-group decrease was observed in the exercise group ($t(13) = 7.64$, $P < 0.001$, Cohen's d = 2.04, 95% CI: –6.8° to –3.7°), while no significant change was detected in the control group ($t(13) = 0.95$, $P = 0.07$, Cohen's d = 0.25) (Figure 4).

Medial Longitudinal Arch (Navicular Drop)

A significant decrease in navicular drop was observed in

Table 2. Outcome Variables: Descriptive Statistics and Test Results

Variable	Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Test	df	*P*-value	η² / r	95% CI of Difference
Knee Valgus Angle (°)	Control	22.07 ± 6.85	18.71 ± 7.70	ANCOVA	1, 26	<0.001	η²=0.35	–11.1 to –3.5
	Exercise	20.07 ± 7.36	10.85 ± 7.07					
Navicular Drop (mm)	Control	12.50 ± 1.45	12.28 ± 1.58	ANCOVA	1, 26	<0.001	η²=0.59	–2.7 to –1.3
	Exercise	12.92 ± 1.49	10.78 ± 1.25					
Ankle Dorsiflexion ROM (°)	Control	11.14 ± 2.10	11.35 ± 2.20	ANCOVA	1, 26	<0.001	η²=0.73	+1.8 to +3.9
	Exercise	10.57 ± 2.20	13.85 ± 2.21					
Knee Proprioception (°)	Control	2.57 ± 0.85	2.42 ± 0.93	ANCOVA	1, 26	<0.001	η²=0.42	–1.6 to –0.3
	Exercise	2.42 ± 0.64	1.35 ± 0.84					
Ankle Proprioception (°)	Control	2.14 ± 0.66	2.00 ± 0.55	Wilcoxon	—	0.31	r=0.19	–0.35 to +0.10
	Exercise	2.00 ± 0.67	1.21 ± 0.69	Wilcoxon	—	0.002	r=0.60	

Mean ± SD of outcome variables at pre- and post-test for both groups. Between-group comparisons were conducted using ANCOVA or Wilcoxon tests, adjusted for baseline. Effect sizes are reported as η² (ANCOVA) and r (Wilcoxon).
Abbreviations: SD = standard deviation; df = degrees of freedom; CI = confidence interval; ROM = range of motion; ANCOVA = analysis of covariance.

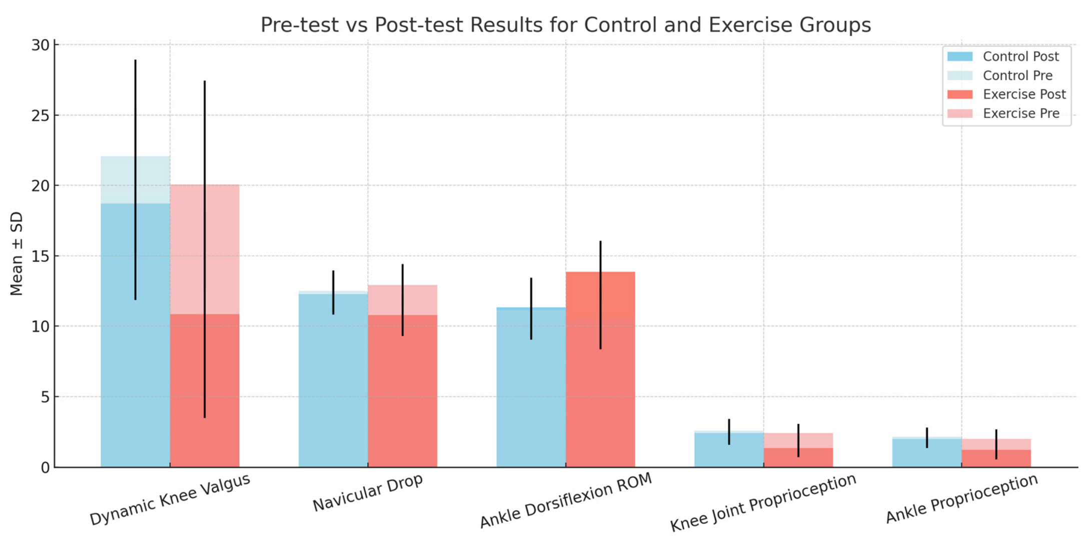

Figure 4. Pre- and post-test comparisons between control and exercise groups (mean ± SD). Between-group differences were analyzed using ANCOVA (for normally distributed variables) and Mann–Whitney U (for ankle proprioception).
Significant improvements in the exercise group were found for:
- Dynamic Knee Valgus ($P = 0.001$)
- Navicular Drop ($P < 0.001$)
- Ankle Dorsiflexion ROM ($P < 0.001$)
- Knee Proprioception ($P < 0.001$)
- Ankle Proprioception ($P = 0.009$)

No significant changes were observed in the control group.

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the exercise group compared to the control group at posttest ($P < 0.001$, $\eta^2 = 0.59$, 95% CI for adjusted mean difference: –5.4 mm to –2.9 mm; see Table 2). Within-group analysis showed a significant reduction in the exercise group ($P < 0.001$, Cohen's d = 2.08, 95% CI: –6.5 mm to –3.6 mm), whereas the control group showed no significant change ($P = 0.180$, Cohen's d = 0.36) (Figure 4).

Ankle Dorsiflexion Range of Motion (DROM)

A significant increase in ankle DFROM was observed in the exercise group compared to the control group at posttest ($P < 0.001$, $\eta^2 = 0.73$, 95% CI for adjusted mean difference: 5.2° to 8.7°) (Table 2). Within-group analysis revealed a substantial improvement in the exercise group ($P < 0.001$, Cohen's d = 2.89, 95% CI: 5.9° to 9.6°), while the control group exhibited no significant change ($P = 0.270$, Cohen's d = 0.31) (Figure 4).

Knee Joint Proprioception

ANCOVA results, controlling for baseline error, revealed a significant improvement in knee joint proprioception in the exercise group compared to the control group at posttest ($P < 0.001$, $\eta^2 = 0.42$, 95% CI for group difference: –1.8° to –0.7°) (Table 2). Within-group analysis showed a marked decrease in joint position error in the exercise group ($P < 0.001$, Cohen's d = 1.47, 95% CI: –2.5° to –1.0°), while the control group showed no significant change ($P = 0.16$, Cohen's d = 0.39) (Figure 4).

Ankle Proprioception (Dorsiflexion)

The Mann-Whitney U test showed no significant between-group difference at pre-test ($P = 0.630$). However, at post-test, the exercise group exhibited significantly better ankle proprioception compared to the control group ($P = 0.009$, r = 0.56, 95% CI: –2.5° to –0.6°). Within-group comparison using the Wilcoxon signed-rank test indicated a significant improvement in the exercise group ($P = 0.002$, r = 0.60). In contrast, the control group showed no significant change ($P = 0.310$, r = 0.19) (Table 2 and Figure 4).

Discussion

This study investigated the effects of a 6-week SFE program on a range of biomechanical and sensorimotor parameters in young females presenting with DKV attributed to distal (ankle) dysfunction. The findings demonstrated significant improvements in DKV angle, navicular drop, ankle and knee proprioception, and ankle dorsiflexion range of motion (DFROM), supporting the efficacy of a distal-focused neuromuscular intervention in enhancing proximal joint alignment and control.

The observed attenuation of DKV aligns with the theory of kinetic chain interdependence, suggesting that foot and ankle function can influence proximal joint mechanics (7).

Biomechanically, improved ankle DFROM may allow for more effective tibial progression during weight-bearing tasks, reducing compensatory knee valgus patterns. Similarly, better medial arch support may limit excessive subtalar pronation, promoting a more neutral alignment at the knee (25). These adaptations support previous assertions by Schwameder (2020) (6) and Babagoltabar & Norasteh (2023) (26), which emphasized the relevance of targeting distal deficits in lower extremity malalignments.

Unlike conventional approaches that emphasize proximal control (eg, hip abductor strengthening) (27), this study adopted a bottom-up strategy emphasizing intrinsic foot musculature and ankle sensorimotor control. This neuromuscular focus may have enhanced joint stiffness regulation and proprioceptive feedback, potentially improving dynamic stability beyond mere strength gains (6).

The significant reduction in navicular drop corroborates the findings of Zarali & Raeisi (2023) (28), Cheng et al (2024) (29), and Okamura (2020) (30), suggesting that intrinsic foot muscle activation through SFE can positively influence medial arch structure. This may reduce the risk of overuse injuries linked to arch collapse, such as tibial stress syndrome or patellofemoral pain, although these outcomes were not directly measured (5, 31). The use of progressively challenging SFE postures (eg, standing on unstable surfaces) may have facilitated neuromotor plasticity and intersegmental coordination (16).

Improvements in ankle and knee joint position sense are consistent with Kim et al (2020) (24), who demonstrated that sensorimotor interventions improve proprioception by enhancing afferent signaling and central processing. Given the interconnected nature of sensorimotor control, improvements in ankle proprioception may indirectly enhance knee joint positioning through more accurate load transmission and feedback mechanisms (27).

However, while positive trends in multiple variables were observed, this study did not examine whether these changes are mechanistically linked. For example, it remains unknown whether improvements in arch height directly contributed to enhanced proprioception or whether both were independent effects of neuromuscular training. Future work should employ path analysis or mediation modeling to explore these interactions.

Additionally, although the authors observed changes that may hypothetically reduce ACL injury risk, such as reduced valgus and better proprioception, ACL-specific outcomes such as knee abduction moment, tibial rotation, or ligament strain were not measured. Therefore, claims regarding ACL injury prevention should be interpreted with caution and limited to theoretical frameworks until validated by longitudinal or biomechanical studies using ACL-relevant markers.

Moreover, the comparisons with prior literature, while present, were largely confirmatory. A more critical analysis is warranted. For instance, unlike studies that combined SFE with hip strengthening (eg, Choi et al, 2019) (32), this study isolated SFE, raising questions about the relative contribution of intrinsic foot function versus proximal reinforcement. Likewise, differences in intervention duration, load intensity, and surface variability across studies could influence outcome magnitude and durability, none of which were explored here.

The enhancement in ankle DFROM, despite the absence of stretching or myofascial release, highlights the potential for neuromuscular strategies to improve joint mobility. This is supported by theories of dynamic soft tissue remod-

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eling through active control and motor learning (26). However, objective measures of tissue compliance or muscle activation patterns were not included, limiting interpretation of the mechanisms underlying mobility gains.

Taken together, the findings underscore the concept of regional interdependence and support the incorporation of distal-focused strategies into comprehensive rehabilitation programs for individuals with DKV. However, conclusions should remain grounded in the observed outcomes and avoid extrapolating beyond the study scope (25).

Limitations

This study has several limitations. First, the small sample size reduces statistical power and limits generalizability, especially to males or older adults. Second, follow-up was limited to the immediate postintervention phase, precluding assessment of the long-term sustainability of observed effects (33). Third, no biomechanical data (eg, 3-dimensional kinematics or kinetics) were collected to confirm the underlying movement changes driving DKV reduction. Fourth, the study did not assess muscle activation (eg, via EMG) or ligament loading, which could provide insight into mechanisms relevant to injury prevention. Finally, although improvements were reported across multiple domains, no multivariate or regression analyses were conducted to assess relationships between them. As a result, the internal coherence and causal pathways among variables remain speculative.

Conclusion

This study provides evidence that SFE can reduce DKV, enhance medial arch integrity, improve joint position sense, and increase ankle DFROM in young females with DKV stemming from distal dysfunction. These findings support the use of bottom-up neuromuscular interventions in lower limb realignment. However, caution is warranted in extrapolating these results to injury prevention contexts (eg, ACL rupture) without direct evidence. Future research should involve larger, more diverse populations, extended follow-up periods, and comprehensive biomechanical analyses to validate these findings and clarify the underlying mechanisms and clinical relevance of such interventions.

Authors' Contributions

Y.M.T. conceptualized and supervised the study. H.M. served as the advisor and contributed to methodological refinement. A.J. conducted the experiments, collected the data, and prepared the initial dataset. A.K. performed the statistical analyses and wrote the manuscript. All authors reviewed, edited, and approved the final version of the manuscript.

Ethical Considerations

The study was approved by the Ethics Committee of the Faculty of Physical Education and Sport Sciences, University of Tehran (IR.UT.SPORT.REC.1402.036). All participants provided written informed consent. Reporting guidelines such as CONSORT and STROBE were not followed.

Acknowledgment

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Conflict of Interests

The authors declare that they have no competing interests.

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