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Impact of lower limb stabilization exercises on ankle balance proficiency in collegiate elite athletes with ankle instability

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Abstract: This study aimed to investigate the effects of lower extremity stabilization exercises, including intrinsic foot muscle, gluteus medius, and combined exercises, on balance performance and ankle instability in elite male athletes with chronic ankle instability. This study included 42 elite male athletes from K University in Seoul. The participants were randomly assigned to the intrinsic foot muscle (n = 14), gluteus medius (n = 14), and combination (n = 14) exercise groups. All groups underwent a six-week intervention program, which was conducted three times per week. Each group underwent a common exercise program in addition to their respective interventions. The assessments included the Cumberland Ankle Instability Tool to assess changes in ankle instability scores and tests to measure static and dynamic balance performance. The results revealed improvements in ankle instability scores across all three groups, with no statistically significant differences between them. Significant improvements in static balance were found in the gluteus medius and combination exercise groups. Additionally, all groups demonstrated significant dynamic balance improvements. Notably, the combination exercise group demonstrated greater changes in both static and dynamic balance compared with the other groups. In conclusion, the combination exercise program, which integrates intrinsic foot muscle and gluteus medius exercises, was more effective in improving ankle instability scores and balance performance than the single-component exercise program. Therefore, combining intrinsic foot muscle exercises with gluteus medius exercises effectively improved ankle stability and overall balance. This approach applies not only to elite athletes but also to the general population as a practical and effective intervention method in clinical settings.

Keywords: *Ankle instability, Balance ability, Combination exercise, Elite athlete, Foot intrinsic muscle exercise, Gluteus medius muscle exercise.*

1. Introduction

Elite collegiate athletes engage in rigorous training to improve their performance, increasing both the intensity and volume of physical activity for competition. However, this increased workload also raises their risk of injury[1]. Injuries pose a significant threat to athletic performance, and some athletes recover and return to peak condition, whereas others are unable to overcome their injuries and are forced to retire[2]. The 2021 Physical Therapy Center statistics at K University in Seoul reported that elite athletes most often experience ankle (20.2%), lower back (12.6%), and knee (10.8%) injuries[3]. The ankle joint is particularly vulnerable to sports injuries because of its crucial role in weight-bearing and controlling lower limb movements during walking and exercise[4]. Recent six-year surveillance data from the National Collegiate Athletic Association (NCAA) revealed that lateral ankle sprains are the most prevalent ankle injuries, with 2,429 cases reported across 25 NCAA sports. Lateral ankle sprains predominantly include anterior talofibular ligament damage, with approximately

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80% of cases also involving the calcaneofibular ligament[5]. These injuries typically occur in the plantar-flexed position during internal rotation or inversion[6]. Research indicates that functional deficits primarily cause lateral ankle sprains, manifesting as pain, swelling, instability, and muscle weakness in the foot and ankle[7]. Approximately 20% of individuals with ankle sprains develop chronic ankle instability (CAI), characterized by recurrent injuries and persistent functional impairments[8]. Impaired proprioception and structural instability due to ligament or soft tissue damageSekir, et al. [9] as well as functional instability due to eversion muscle dysfunction are the underlying causes of CAI[10]. Given these factors, elite athletes need to engage in rehabilitation programs that focus on strengthening the ankle, improving proprioception, and restoring the joint range of motion. Functional training to improve balance and stability is essential for recovering from injuries and returning to competitive activity[11]. The ankle joint plays a pivotal role in maintaining postural stability, depending on the integration of visual, vestibular, and proprioceptive inputs to control body sway[12, 13]. Postoperative or postinjury rehabilitation aims to strengthen the muscles of the ankle and toes while improving balance and proprioception to restore functional stability and enable a return to preinjury activity levels[14]. Proprioceptive exercises performed on stable and unstable surfaces have improved ankle stability and reduced the risk of reinjury[15]. The arch of the foot plays a crucial role in providing structural stability and elasticity. Intrinsic foot muscle training is one effective method for enhancing foot stability[16]. These muscles support the medial longitudinal arch, assist in maintaining balance during standing and walking, and function as a spring to preserve the arch's shape[17]. Further, they stabilize the ankle during a single-leg stance[18]. Recent studies have revealed that short foot exercises (SFEs), which target the intrinsic foot muscles, significantly improve dynamic balance, ankle instability, and somatosensory function. In particular, Lee et al. conducted an eight-week, three-times-per-week intervention that involved 30 individuals with ankle instability, categorizing them into the SFE and proprioceptive exercise groups. The SFE group demonstrated statistically significant improvements in all balance measures (anterior–posterior [AP] and medial–lateral [ML]) compared with the proprioceptive exercise group ($p< 0.05$)[19]. Further, lateral ankle ligament injuries compromise lower limb stability. Mackinnon and Winter reported decreased strength in the hip abductors and adductors postinjury, which increases the likelihood of recurrent ankle sprains[20]. Gluteus medius weakness, in particular, contributes to lower limb malalignment and impaired stability during single-leg stance, as this muscle plays a crucial role in pelvic stabilization during walking[21]. Lentell indicated the necessity of gluteus medius strengthening for improving ankle stabilityLentell, et al. [22] whereas Beckman reported that CAI is closely associated with reduced gluteus medius strength, as determined through electromyography analysis[23]. These results indicate that gluteus medius strengthening programs could be a foundational component of acute ankle sprain rehabilitation[24]. Traditional treatment approaches for ankle sprains typically include conservative management, such as range-of-motion exercises, pain control, and bracing during the early phase, followed by strengthening and proprioceptive exercises during the intermediate phase, and agility and plyometric training during the final phase[25]. However, these approaches frequently focus solely on the ankle joint, thereby neglecting the need for comprehensive rehabilitation to prevent reinjury and improve overall stability[26]. To address these gaps, this study aimed to assess the effects of intrinsic foot muscle, gluteus medius, and combined exercises on overall ankle balance performance and instability in elite male athletes with CAI.

2. Materials and Methods

2.1.Study Design and Sample

This study included 42 male collegiate elite athletes in their 20s, enrolled at K University in Seoul. Inclusion criteria were no significant musculoskeletal or neurological disorders, no history of orthopedic conditions or surgeries involving the knee or hip, no ankle surgeries within the past 2 months, and no limitations in ankle range of motion. This study excluded participants with less than 80% attendance during the study period. The sample size was calculated using G*Power version 3.1.9.7, with a significance level of 0.05, statistical power of 0.8, and an effect size of 0.5 for one-way analysis of variance (ANOVA), causing a minimum required sample size of 42 participants. This study initially recruited 45 participants; however, 3 participants were excluded due to injuries sustained during the experiment. Hence, the final analysis included 42 participants. Table 1 shows the general characteristics of the study participants.

Table 1.
General characteristics of study participants.

variable	**IEG**	**CEG**	***p***
Age (years)	21.36 ± 1.08a	21.64 ± 1.2a	0.253
Height (cm)	180.9 ± 6.8	177.4 ± 5.9	0.134
Weight (kg)	78.43 ± 18.2	76.29 ± 17.5	0.039
a mean ± SD			
IEG: intrinsic muscle exercise group; GEG: gluteus medius exercise group; CEG: combination exercise group			

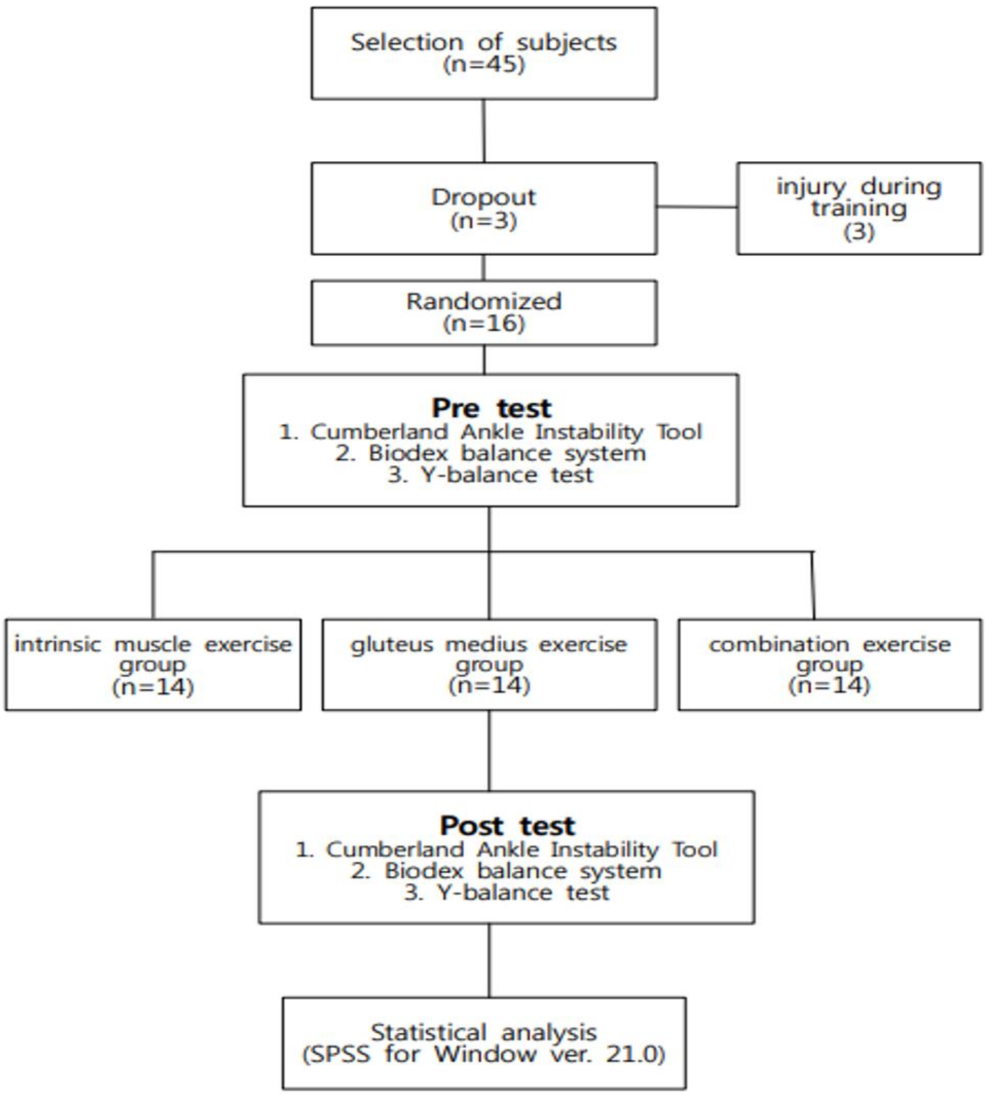

Figure 1.
Flow diagram of the study.

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2.2. Measures

2.2.1. Ankle Instability Assessment (Cumberland Ankle Instability Tool [CAIT])

The CAIT was utilized to assess ankle instability, with a score of 24 or below indicating instability. The CAIT consists of nine questions, with a maximum score of 30 points. Scores of 28 points or higher indicate stable ankles, whereas scores of 24 points or below denote unstable ankles. Higher scores represent better ankle stability, whereas lower scores indicate greater instability[27]. Previous studies well established the reliability and validity of this questionnaire, with an intraclass correlation coefficient (ICC) of 0.96 [27].

2.2.2. Static Balance Assessment

In this study, Balance System SD (Biodex, USA, 2009) was used to assess the static balance ability. The device consists of a balance platform and a display unit. The platform is equipped with 12 strain gauges that measure the tilt angle and platform balance. The balance platform tilts up to 20° in any direction, with the tilt angle representing the static balance stability level. Static balance tests were conducted within a restricted range of 5°. The balance scores were categorized into AP, ML, and overall stability components. Lower scores indicate better ankle stability, as lower tilt angles and platform balance readings reflect improved control. The intrarater reliability of this measurement method was reported as $r = 0.80$[28].

2.2.3. Dynamic Balance Assessment

The Y-Balance Test (YBT) is utilized to assess lower limb flexibility, strength, and dynamic balance. It is a simplified version of the Star Excursion Balance Test (SEBT), which originally included eight directions. The YBT focuses on three specific directions—anterior, posterolateral, and posteromedial—which have demonstrated high reliability (ICC = 0.91) for identifying individuals with CAI[29].

2.3. Interventions

2.3.1. Common Exercise Program

Table 2 presents the common exercise program used in this study. This program was adapted according to the comprehensive 4-week rehabilitation program for individuals with CAI developed byHale, et al. [30] the methods described in *Orthopedic Rehabilitation of the Athlete*Reider [31] and the exercises outlined by Seo [32] which focused on the effects of gluteus maximus and medius strengthening on balance in patients with CAI[32].

2.3.2. Intrinsic Muscle Exercise Group Program

1. SFE: The SFEs involve drawing the first metatarsophalangeal joint toward the calcaneus while ensuring that the phalanges do not flex, thereby isolating the intrinsic foot muscles. This technique shortens the foot by elevating the medial longitudinal arch. Before performing the exercise, the participants were instructed not to curl or extend their toes and were guided to maintain the subtalar joint, calcaneus, and metatarsal heads in a neutral position[33]. The exercise was performed in three sets of 15 repetitions, with each contraction held for 3 s.
2. Towel Curl Exercise: The towel curl exercise is an effective method for strengthening the plantar muscles, particularly the short toe flexors, and helps improve the height of the foot arch. To perform this exercise, the participants spread a damp towel on the floor and used their toes to scrunch the towel, then released it repeatedly. The exercise was performed in three sets of 1 min each[33].

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Table 2.
Common Exercise (n = 42).

Warm up Jogging for 10 min.	
Main exercise	Ankle dorsiflexion/plantar flexion with theraband/15 repetitions 4 sets
	Ankle inversion/eversion with theraband/15 repetitions 4 sets
	Double-leg bridge/15 repetitions 4 sets
	Standing heel raised/15 repetitions 4 sets
	Split squat/12 repetitions 4 sets
Cool down Ankle stretch 5 min	

2.3.3. Gluteus Medius Exercise Group Program

1. Straight Leg Raise (SLR): Hip abduction in a side-lying position is the most effective exercise for activating and strengthening the gluteus medius[34]. For the SLR, participants lay on their side on a mat while maintaining a neutral posture. To ensure proper pelvic alignment, the lower leg was bent while keeping the upper leg straight. The upper leg was abducted to a range of motion of 30° and then returned to the starting position. This exercise was performed in four sets of 15 repetitions.
2. Clamshell Exercise: The clamshell exercise is an excellent non-weight-bearing exercise predominantly utilized in early rehabilitation to strengthen the gluteus medius[35]. Proper spinal and pelvic alignment must be maintained in a straight line without any unnecessary movement[36]. For this exercise, the participants lay on their side on a mat, maintaining a neutral posture. The hip was flexed to 60° and the knees to 90°. While keeping the feet together, the participant abducted the top knee and maintained the neutrality of the spine and pelvis. This exercise was performed in four sets of 15 repetitions.

2.3.4. Combination Exercise Group

The combination exercise group performed both the SFE and the SLR. The SFE was conducted in four sets of 15 repetitions, with each contraction held for 3 s. The SLR was performed in four sets of 15 repetitions.

2.4. Data Analysis

Statistical Package for the Social Sciences version 20 for Windows was used to analyze all data collected in this study. Normality was assessed using the Shapiro–Wilk test ($p \leq 0.05$), and descriptive statistics were utilized to analyze the general characteristics of the participants. Paired *t*-tests were conducted to assess the significance of pre- and postintervention differences within each group. One-way ANOVA was conducted to evaluate the differences in change scores among the groups pre- and postintervention. Additionally, Scheffe's post hoc test was used to investigate differences in the changes between the pre-- and postintervention outcomes. The significance level was set at α of 0.05.

3.Result

3.1. Comparison of Height Between Both the Groups After Intervention

3.1.1. Comparison of Pre- and Postintervention Ankle Instability Scores

Table 3 presents the pre- and postintervention results for each exercise group. Additionally, no significant differences in the CAIT scores were observed among the three groups.

Table 3.
Comparison of Before and After the Cumberland Ankle Instability Score.

	Pretest	**Posttest**	**t**	***P***
IEG	20.64 ± 2.2a	27.57 ± 1.55	−13.945	0.001***
GEG	21.43 ± 2.1	28.36 ± 0.84	−14.266	0.001***
CEG	22.07 ± 2.09	28.79 ± 0.97	−10.200	0.001***

Note: $p < 0.05$, *** $p < 0.001$
a mean ± SD
IEG: intrinsic muscle exercise group; GEG: gluteus medius exercise group; CEG: combination exercise group

3.1.2. Comparison of the Pre- and Postintervention Static Balance Ability
3.1.2.1. Intrinsic Foot Muscle Exercise Group

No significant differences in the static balance scores pre- and postintervention were observed in the intrinsic foot muscle exercise group ($p > 0.05$). Additionally, no significant changes were found in the overall, ML, or AP balance scores ($p > 0.05$; Table 4).

Table 4.
Comparison of overall, ML, and AP scores in the foot intrinsic muscle exercise group.

	Pretest	**Posttest**	**t**	***p***
overall	2.81 ± 0.69a	2.72 ± 0.68	1.964	0.08
ML	2.1 ± 0.67	2.0 ± 0.63	1.247	0.24
AP	1.39 ±0.28	1.34 ± 0.27	1.464	0.17

Note: A mean ± SD
ML: medial–lateral; AP: anterior–posterior.

3.1.2.2. Gluteus Medius Exercise Group

A significant difference in the overall static balance score pre- and post-intervention was observed in the gluteus medius exercise group ($p < 0.05$). However, no significant differences were found in the ML or AP balance scores ($p > 0.05$; Table 5).

Table 5.
Comparison of the overall, ML, and AP scores of the gluteus medius exercise group.

	Pretest	**Posttest**	**t**	***p***
overall	3.66 ± 1.49a	2.81 ± 0.85	2.409	0.03*
ML	2.91 ± 1.41	2.16 ± 1.03	2.884	0.18
AP	1.70 ±0.90	1.53 ± 0.22	0.482	0.64

Note: * $p < 0.05$
a mean ± SD
ML: medial–lateral AP: anterior–posterior.

3.1.2.3. Combination Exercise Group

Significant differences in the overall and ML static balance scores pre- and post-intervention were observed in the combination exercise group ($p < 0.05$). However, no significant difference was found in the AP balance score ($p > 0.05$; Table 6). Additionally, the changes in the static balance scores among the three groups were statistically significant ($p < 0.05$). Post-hoc analysis revealed that the combination exercise group demonstrated greater reductions in the overall and ML balance scores compared to the intrinsic foot muscle exercise group, with significant differences observed between them ($p < 0.05$; Table 7).

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Table 6.
Comparison of the combination exercise group overall, ML, and AP scores.

	Pretest	Posttest	t	*p*
overall	3.66 ± 1.03a	2.19 ± 0.54	4.94	0.001***
ML	2.72 ± 1.13	1.90 ± 0.65	2.399	0.04*
AP	1.70 ±0.65	0.99 ± 0.15	3.356	0.08

Note: * $p < 0.05$, *** $p < 0.001$
a mean ± SD
ML: medial–lateral; AP: anterior–posterior

Table 7.
Comparison of change values between the static balance groups.

variable	IEG (n = 14)	GEG (n = 14)	CEG (n = 14)	F	*p*
overall	0.1	0.81	1.50	9.61	0.001***
ML	0.82	0.72	0.91	3.96	0,03*
AP	0.06	0.17	0.69	2.41	0.1

Note: * $p < 0.05$, *** $p < 0.001$
a mean ± SD
ML: medial–lateral; AP: anterior–posterior; IEG: intrinsic muscle exercise group; GEG: gluteus medius exercise group; CEG: combination exercise group

3.1.3. Comparison of the Pre- and Postintervention Dynamic Balance Ability

Significant differences in YBT scores were observed pre- and postintervention across all groups. The intrinsic foot muscle exercise group demonstrated significant improvements in YBT scores ($p< 0.001$), as did the gluteus medius ($p< 0.001$) and combination exercise groups ($p< 0.001$; Table 7). Further, the changes in dynamic balance scores among the three groups were statistically significant ($p< 0.001$). Post-hoc analysis revealed that the combination exercise group exhibited greater increases in dynamic balance scores compared to the intrinsic foot muscle and gluteus medius exercise groups, with significant differences among them ($p< 0.001$). Furthermore, the changes in the dynamic balance scores among the three groups were significant ($p< 0.001$; Table 8). Post-hoc analysis confirmed that the combination exercise group demonstrated significantly greater improvements in the dynamic balance scores compared to the other two groups ($p< 0.001$).

Table 7.
Comparison of the dynamic balance ability scores.

Variable	IEG (n = 14)	GEG (n = 14)	CEG (n = 14)	F	*p*
Overall	7.38	8.17	12.9	17.0	0.001***

Note:* $p < 0.05$, *** $p < 0.001$
a mean ± SD
IEG: intrinsic muscle exercise group; GEG: gluteus medius exercise group; CEG: combination exercise group

Table 8.
Comparison of change levels between the dynamic balance.

	Pretest	Posttest	t	*p*
IEG	89.50 ± 5.95a	97.89 ± 5.82	−12.280	0.001***
GEG	88.35 ± 8.55	95.61 ± 7.80	−7.139	0.001***
CEG	86.52 ± 8.24	98.99 ± 6.80	−13.379	0.001***

Note:* $p < 0.05$, *** $p < 0.001$.
a mean ± SD
IEG: intrinsic muscle exercise group; GEG: Gluteus medius exercise group; CEG: combination exercise group

4. Discussion

Various This study investigated the effects of intrinsic foot muscle, gluteus medius, and combined exercises on ankle instability scores, static balance ability, and dynamic balance ability in collegiate elite athletes. Athletes with CAI were categorized into the intrinsic foot muscle, gluteus medius, or combined exercise groups, and the intervention effects were compared among the groups.The results revealed that all three groups demonstrated improvements in ankle instability scores, with no significant differences observed among them. These results are congruent with a study by Kim Tae-gyu, which demonstrated that the use of the CAIT for functional assessment during rehabilitation in elite athletes with CAI helped improve their self-awareness and optimize injury prevention[37].

In terms of balance ability, all three groups demonstrated significant improvements in dynamic balance. However, the intrinsic foot muscle exercise group demonstrated no significant changes in static balance, whereas those of the gluteus medius and combination exercise groups were significantly improved. These results are consistent with the findings of Mignogna, who revealed significant improvements in dynamic balance as measured by the YBT after SFE[38]. Similarly, Lynn et al. observed improved dynamic balance ($p< 0.01$) but no significant changes in static balance after four weeks of SFE in healthy adults[39].

The lack of significant changes in static balance in the intrinsic foot muscle exercise group may be attributed to the unique characteristics of elite athletes, whose habitual high physical activity levels may mask the benefits observed in general populations. For instance, SFEs have improved the medial longitudinal arch and shifted the center of pressure laterally in individuals with flat feet, thereby improving static balance stability[40]. However, this effect may be less pronounced in elite athletes.

Additionally, Hatem Jaber demonstrated lower gluteus medius activation in individuals with CAI compared to those withoutJaber, et al. [41]. Smith, et al. [42]revealed that strengthening the gluteus medius in patients with CAI improved static balance, as indicated by reduced error scores in the Balance Error Scoring System, along with dynamic balance improvements[42]. Furthermore, Leavey and Sandrey observed significant improvements in the SEBT among collegiate soccer players after six weeks of proprioceptive and gluteus medius exercises, compared with the single-component exercise groups[43].

These results indicate that the significant improvements in static and dynamic balance observed in the gluteus medius and combination exercise groups may be attributed to the role of the gluteus medius in maintaining balance. The gluteus medius is a crucial stabilizer during single-leg stance, compensating for restricted ankle movement and playing an essential role in posture control. Notably, the combination exercise group showed significantly greater improvements in static balance (overall and medial–lateral scores) compared with the intrinsic foot muscle exercise group. Additionally, the combination exercise group demonstrated significantly greater improvements in dynamic balance compared with both the intrinsic foot muscle and gluteus medius exercise groups.This aligns with the results of Favejee et al., who revealed that intrinsic foot muscle exercises positively influence somatosensory control of posture and balance by affecting plantar skin receptors, foot and ankle muscles, and tendon proprioceptors[44]. Furthermore, studies have revealed that hip muscle preactivation, including the gluteus medius, minimizes postural sway and improves balance during single-leg stance[45]. These results indicate that combining intrinsic foot muscle and gluteus medius exercises could enhance both static and dynamic balance ability.

Several studies have investigated the effects of intrinsic foot muscle and gluteus medius exercises on balance and ankle stability in general populations or patients with CAI; however, research on elite athletes, who are at a higher risk of ankle injuries, is lacking. This study addressed this gap by assessing the effects of these interventions on elite male athletes with CAI. The results indicated that all three groups exhibited improved ankle instability scores and dynamic balance, whereas static balance was significantly enhanced only in the gluteus medius and combination exercise groups. Among these, the combination exercise group showed the greatest improvements in both static and dynamic balance.

These results provide a scientific basis for incorporating intrinsic foot muscle and gluteus medius exercises into rehabilitation programs for elite athletes with CAI. The combined exercise program may be particularly effective for preventing ankle injuries and improving balance in the early rehabilitation stages.

This study was limited to male collegiate elite athletes in their 20s. Additionally, controlling for the effects of participants' sport-specific training during the intervention period presented a challenge, and the application of the exercise programs may have differed based on individual recovery and physical abilities. Future research is recommended to address these limitations by including diverse populations and investigating long-term outcomes to further assess the effectiveness of these interventions in preventing injuries and supporting rehabilitation in elite athletes.

5. Conclusion

Various This study investigated the effects of intrinsic foot muscle, gluteus medius, and combined exercises on ankle instability and balance ability in elite male athletes in their 20s. This study revealed the following results:

1. All groups demonstrated ankle instability score improvements but with no significant differences among them.
2. The intrinsic foot muscle exercise group showed significant dynamic balance ability improvements between pre- and postintervention; however, no significant changes were observed in the static balance ability.
3. The gluteus medius exercise group exhibited, significantly improved dynamic balance ability between pre- and postintervention. For static balance ability, a significant difference was observed in the overall score, but no significant changes were noted in the ML and AP scores.
4. The combination exercise group showed significant static balance ability improvements pre- and postintervention. Significant differences were observed in the overall and ML static balance scores but with no significant changes in the AP score.
5. All three groups exhibited significant improvements in the dynamic balance ability between pre- and postintervention, with significant differences among the groups.
6. The combination exercise group demonstrated significantly greater improvements in both static and dynamic balance abilities compared with the intrinsic foot muscle and gluteus medius exercise groups.

Based on these results, the combined exercise program, which integrates intrinsic foot muscle exercises and gluteus medius exercises, could be utilized as an effective early rehabilitation or primary prevention method for ankle instability. Furthermore, this study provides foundational evidence for preventing ankle injuries among elite athletes.

Future studies are recommended to focus on developing and designing various treatment and exercise programs for injury prevention in elite athletes, considering gender differences and incorporating long-term follow-up assessments.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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