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Pamukkale J Sport Sci, 15(1), 59-72, 2024 **Research Article**

Enhancing Athletes' Foot Stability: A Comparative Analysis of Gluteus Maximus and Gluteus Medius Muscle Strengthening Effects on Navicular Drop, Balance, and Foot Posture Index in Over-Pronated Foot

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ABSTRACT

This study aimed to determine the effectiveness of gluteus maximus versus gluteus medius muscle strengthening exercises on the navicular drop (ND), balance, and foot posture index (FPI 6) among athletes with over-pronated feet. A pre-post experimental study design with a total of 54 athletes with bilateral over-pronated feet were randomly assigned into group A (n=18), group B (n=18), and group C (n=18). Medial longitudinal arch height (MLA) was assessed with the Navicular Drop Test, the static and dynamic balance was determined with the stork stance test (SST) and modified Star Excursion Balance Test, and Foot Posture was assessed with Foot Posture Index 6. Multivariate Repeated measures ANOVA was used to analyze the effects of gluteus maximus versus gluteus medius muscle strengthening and short foot exercises. At four weeks, the gluteus medius along with short foot exercises (group B) showed significantly less ND and FPI 6 while showing more excellent SST and modified SEBT than the gluteus maximus muscle strengthening along with short foot exercises (group A) and control group (group C). These results suggest that adding gluteus medius muscle strengthening exercises to short foot exercises (SFE) was more effective in supporting the medial longitudinal arch and improving balance than performing SFE alone.

INTRODUCTION

Overuse injuries arise when tissue is damaged by recurrent stress on bone and musculotendinous tissues at a rate that exceeds the body's ability to recover them. Athletes are more susceptible to overuse injuries due to a confluence of intrinsic or anatomical factors such as ligamentous laxity, flexibility deficits, and bone alignment of the limbs, as well as extrinsic ones, including environmental and training faults (Krivickas et al., 1997). Two of the many risk factors for injury in athletics are balance and foot position, which have been the subject of much research (Nicholas & Marino, 1987). Ankle injuries are the most common type of injury in different sports, leading to significant loss of playing time (Robbins & Waked, 1998). Ankle sprains account for 10% to 45% of running and jumping injuries, and there are roughly 27,000 ankle sprains per day in the US, or one for every 10,000 persons (Hintermann & Nigg, 1998).

Running is one of the most common activities that lead to lower extremity overuse injuries (Ferber et al., 2009). According to many epidemiological studies, about 27% and 70% of recreational and competitive distance runners suffer from an overuse injury at some point each year (Ferber et al., 2009). Anatomical or biomechanical anomalies, lack of flexibility, lack of strength, muscular imbalance, shoe type and/or the use of orthotics, and the kind of running terrain are the most frequent causes of foot and ankle injuries from running (Hintermann & Nigg, 1998). Lower extremity stress fractures have frequently been linked to improper lower extremity posture and/or over-pronation (Nur Saibah, 2020).

Over-pronation is a dysfunctional movement when the foot must turn excessively in from its neutral line. The medial portion of the foot may, therefore, wind up supporting most of the body's weight. In this instance, the body is supported during toe-off by the big toe and the second toe of the foot rather than the ball of the foot. When the range of motion exceeds 15° angle when walking (heel strike and push-off) and exceeds 5° angle when standing, it is frequently characterized as over-pronation (Kernozek & Richard, 1990). According to biomechanical research, changed lower limb alignment can result in dramatic changes in foot posture and function (Riskowski et al., 2013). If not appropriately treated, overpronation and over-supination can lead to future injury and chronic function instability of the foot, such as ankle and subtalar joint instability. Furthermore, Mitchell et al. (2008) believe that an unstable subtalar joint has a slower reaction time to generate an ankle sprain mechanism than a stable joint (Mitchell et al., 2008).

However, foot alignment may additionally be affected by the strength and function of the proximal muscles of the lower extremity (Chuter & Janse de Jonge, 2012). With hip abductor and external rotator muscle strengthening for six weeks, a study on asymptomatic individuals with flatfoot showed a decrease in hindfoot eversion range of motion (Snyder et al., 2009). According to Seshan et al. (2021), excessive internal hip rotation results from the weakening of the hip stabilizers (hip extensors, abductors, and external rotators), which leads to foot pronation. Reactivating the gluteal muscles will restore correct muscular recruitment patterns, enhancing strength and performance (Seshan et al., 2021).

Over-pronated feet are common among runners and can lead to alteration in lower limb biomechanical alignment, predisposing the individual to injuries and decreasing athletic performance. Strengthening of gluteus maximus and gluteus medius has been found to treat over-pronated feet among healthy adults (Engkananuwat & Kanlayanaphotporn, 2023; Goo et al, 2016). A study of strengthening of the gluteus maximus and gluteus medius to correct over-pronated feet among runners will help the physiotherapist as a guidance stone for using either muscle strengthening.

There are studies on excessive pronation among athletes in the literature. However, there is limited literature on the efficacy of gluteus maximus and gluteus medius strengthening to correct over-pronated feet among athletes. A comparative study of the efficacy of gluteus maximus and gluteus medius strengthening to correct over-pronated feet among athletes will help determine which treatment is superior to the other.

This research and study are intended to:

To find out the efficacy of gluteus maximus muscle strengthening on Navicular drop, Balance. Foot posture index among athletes with over-pronated feet. To find out the efficacy of gluteus medius muscle strengthening on Navicular drop, Balance. Foot posture index among athletes with over-pronated feet.

METHODS

Participants

This pilot study was conducted at Tau Devi Lal Stadium, Gurugram, Haryana-122001. Fifty-four athletes included in this study were individuals identified with bilateral over-pronated feet. The study adhered to the principles outlined in the Declaration of Helsinki. Participation in the study was voluntary, and participants received written and oral explanations regarding their participation and the importance of providing accurate information. Before allocating the exercises, the muscle strength was tested by means of manual muscle testing. Then the participants were randomly allocated to Gluteus Maximus Muscle strengthening along with short foot exercises (Group A = 18), Gluteus Medius Muscle

Strengthening along with short foot exercises (Group B =18) and Control group (Group C = 18), here by the term "Short foot exercises" mean a particular exercise to strengthen the foot intrinsic muscles. The chit method was used for random allocation. It was a single-blinded study, as the participants were unaware of the intervention, while the accessor was aware of the treatment being given to the subject. The selection criteria of the participants were both genders, between 18 to 30 years of age, with asymptomatic bilateral over-pronated feet with a navicular drop more significant than 10mm (Goo et al., 2016) and a positive foot posture index (Mulchandani et al., 2017) The following conditions were considered grounds for exclusion from the study: discomfort, any structural deformities of the spine or lower extremities, neuromuscular diseases, visual, speech, or hearing impairments, or those having a prior history of foot/ankle fractures or surgery (Goo et al., 2016). The anthropometric data of athletes are mentioned in (Table 1). All parameters reported large effect size (partial eta squared) as mentioned in (Table 3).

Table 1
Anthropometric Data of Athletes (Runners)

Parameters	**Experimental Group A (N=18)**		**Experimental Group B (N=18)**		**Control Group C (N=18)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
AGE (in years)	20.56	1.88	21.06	2.36	20.78	1.98
Height (in centimeters)	169.1	10.1	171.4	10.4	169.0	9.35
Weight (in kilograms)	63.11	9.88	61.67	14.4	59.5	12
BMI (kg cm-2)	22.08	2.54	20.7	2.88	20.68	2.74
LLD R (cm)	89.01	8.06	88.08	10.8	89.57	9.56
LLD L (cm)	88.71	8.55	88.3	11.3	89.94	9.73

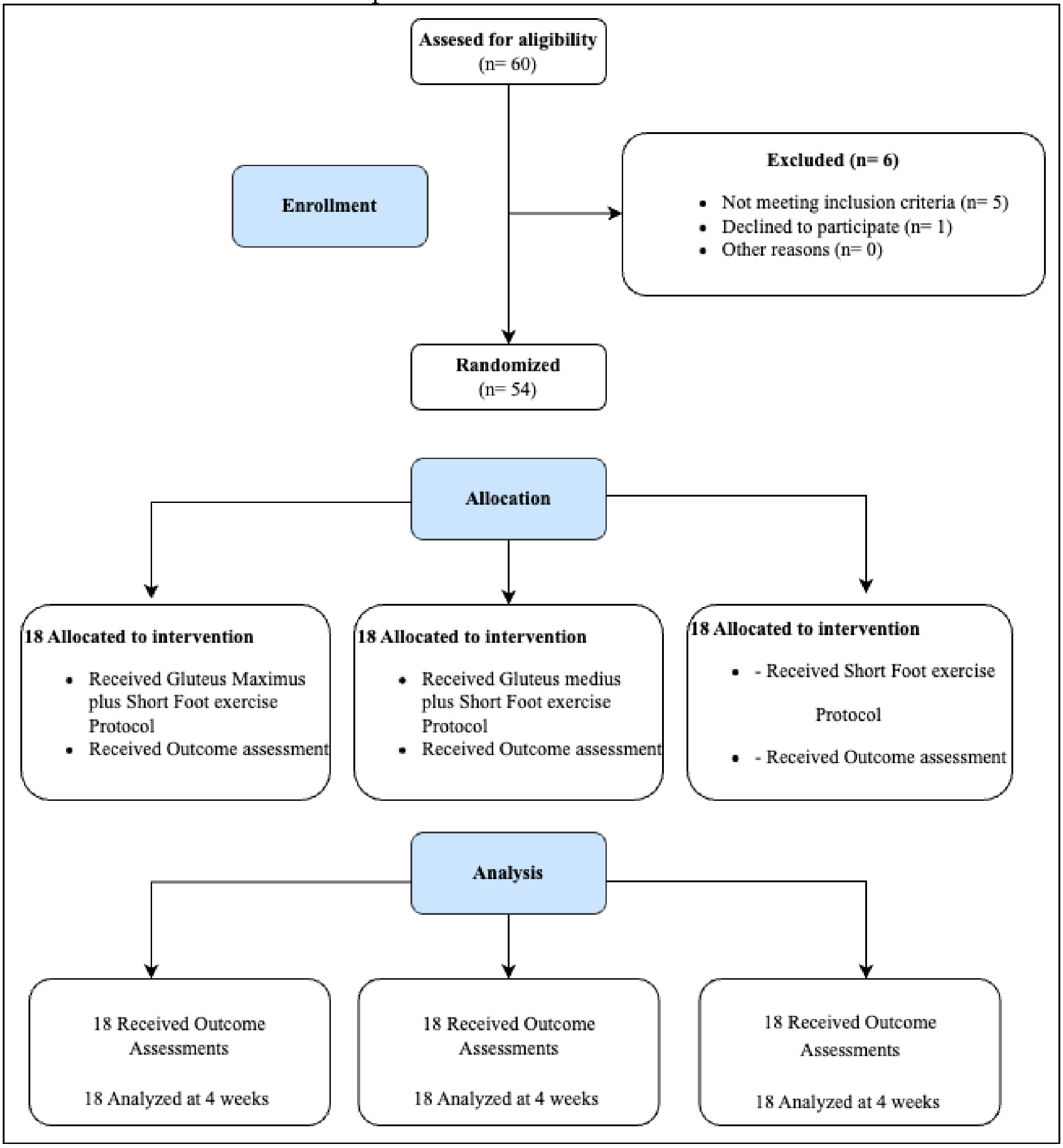
Note. Group A - Gluteus Max Strengthening + Short Foot Exercises; Group B - Gluteus Med. Strengthening+ Short Foot Exercises; Group C - Short Foot Exercises; SD – Standard Deviation.

The study was performed according to (Figure 1) displays a CONSORT diagram showing the flow of participants through each stage of the study.

Procedures

Inclusion and exclusion criteria were used to choose subjects. The individuals were split into three groups using simple random selection and random allocation.

Figure 1
CONSORT Flowchart of Participants

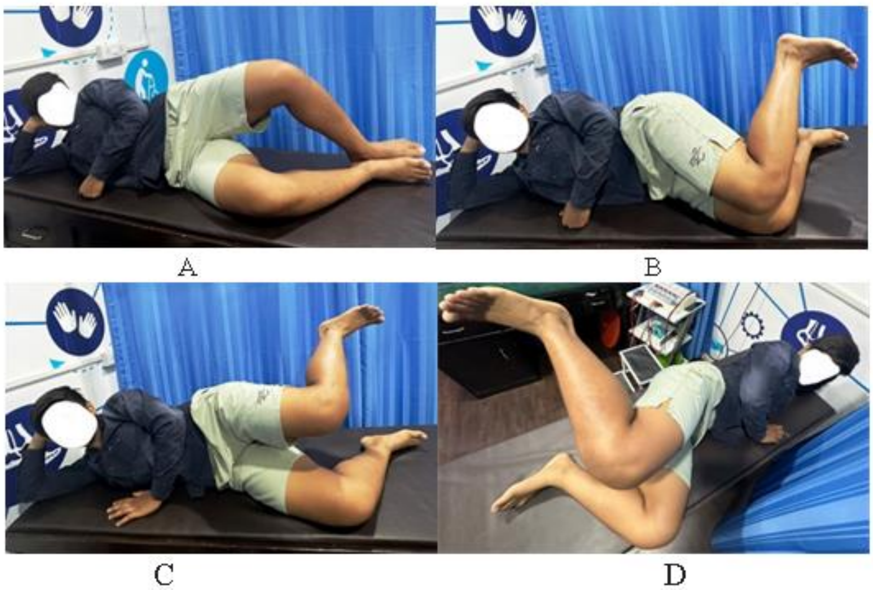


All outcome variables were evaluated at the beginning of the study in the following order for each subject: Navicular Drop Test, Static Balance, Dynamic Balance, and Foot Posture Index. The participants were given a rest time of one minute each between the given tests. A training session was held to ensure that the participants understood the progressions and how to appropriately do the exercises to do the exercises appropriately. The home exercises were given to the participants. Three times weekly observations were made to ensure that they were carried out precisely and with the correct form, where the patient performed the exercises while being on a video call, where the postural corrections were elaborated. Exercises were corrected from time to time, in which case the accessor was the same person who provided the training to the participants. Visits to the academy were made three times a week to accomplish this. All participants had to come to the clinic twice: once at the beginning and once after four weeks to get the outcome measurements and review the activities.

Exercises to strengthen the gluteus maximus were performed in the experimental group (Group A) while lying on one is back with the leg flexed to 90 degrees. The patients were told to maintain their knee flexion at 90 degrees and hip abduction at 30 degrees. The person was told to move their hip away from the plinth, and measurements were taken using a goniometer. For four weeks, these exercises were performed six days a week for 20 repetitions (Goo et al., 2016).

The second experimental Group, Gluteus Medius Muscle Strengthening Exercises (Group B), included exercises to increase strength, and four progressions were applied. Progressions one through three were performed with the exercising leg on top, the hips flexed 45 degrees, the knees slightly flexed, and the feet together, and measurements were taken using a goniometer. The hip was held in a slightly extended position for Progression 4, as shown in (Figure 2). Every exercise in the sequence was done for ten repetitions with a 10-second break between each set. For four weeks, the workout was done six days a week (Engkananuwat & Kanlayanaphotporn, 2023).

Figure 2
Hip Abductor Exercise: Progressions A-*D*



The Control Group / Short Foot Exercises (Group C) consisted of subjects following an intrinsic muscle-strengthening protocol. The short foot exercise has been found to effectively strengthen the intrinsic foot muscles (Mulligan & Cook, 2013; Unver et al., 2019). The participants were instructed to draw the metatarsal heads back towards the heel and hold the position for five sec without the toes curling. The SFE progressed over three phases, beginning in a seated position before advancing to a double-leg stance and single-leg stance (Engkananuwat & Kanlayanaphotporn, 2023).

Data Collection Tools

Navicular Drop Test

The medial longitudinal arch is assessed for capacity by utilizing the navicular drop test. The navicular tuberosity moves a certain distance when standing as the subtalar joint transitions from neutral to relaxed. Subjects sat with their feet flat on a hard surface; knees extended to 90 degrees, and ankle joints in a neutral posture for the Navicular drop test. Keeping the sub-talar joint in a neutral position, the most prominent position of the navicular tuberosity was identified and marked with a marker. The card should be vertically inserted into the navicular bone inside the back foot as it is viewed from the ground. Finally, the difference between the original navicular tuberosity heights and a measuring tape was used to quantify the magnitude of the navicular decline (Adhikari et al., 2014).

Static Balance

The static balance was tested using the stork stand balance technique. The stork test monitors an individual's progress in maintaining a condition of equilibrium (balance) in a static position. The Stork test required the person to lift one leg and lay their toes on the knee of the other leg while standing comfortably on both feet and with their hands on their hips. The patient was instructed to raise their heel whenever necessary by standing on their toes. The stopwatch started when the heel was lifted off the ground (Kranti Panta, 2015).

Dynamic Balance

Utilizing the Modified Star Excursion Test (mSEBT), Dynamic Balance was assessed. The participant's leg was measured before the test. In the supine position, measure the length of the limb from the anterior superior iliac spine to the medial malleolus. At the center of the testing grid, participants stand barefoot in a double-limb stance (i.e., with their feet together). Participants try to cover the most significant distance possible in each direction with the part of their reaching foot that is furthest away from them, make touch with the directional line, and then make their way back while remaining balanced on the support. The trial is complete when the individual resumes a double-limb stance following the reach. The acquired distance, commonly measured in centimeters, displays how the stance limb performs dynamically in terms of postural alignment (Picot et al., 2021). The normalized scores will be calculated for each direction according to the formula: *"Normalized score (%) = (reach distance cm/limb length* *cm) / 100"*. Composite Score Calculation: *"Composite score* = *(normalized ANT* + *normalized PM* + *normalized PL)/3."*

Foot Posture Index

The foot posture index (FPI) is the most accurate tool for categorizing patients into overpronation, over-supination, and normal groups. While the six variables listed below were measured, subjects were advised to stand still, barefoot, with their arms at their sides and their heads straight. Encourage the patient to move around the room while marching before settling into a relaxed standing position. (Nur Saibah, 2020) Figure 3 illustrates the criteria for calculating the foot posture index 6.

Figure 3
The Foot Posture Index 6 Criteria

Data Analysis

The gathered data was analysed using the IBM Statistical Package for Social Sciences 27 (SPSS) program. The data was found distributed uniformly, as shown by the Shapiro-Wilk test. One-way ANOVA was used to compare all variables between groups at baseline. Multivariate Repeated Measures ANOVA was used to compare all the variables pre and post intervention in the three groups. Post-hoc analysis was done for multiple comparisons (Tukey HSD) to make pairwise analysis. Partial eta square values for all outcome variables for significant time*group interaction effects were calculated.

RESULTS

All 54 participants completed the 4-week intervention. All outcomes at four weeks changed significantly from baseline (p<0.001; Table 2). Gluteus medius strengthening along with short foot exercises (Group B) increased significantly from baseline, and this increase was significantly more significant than groups A and C at four weeks (p<0.001). The pre and post Navicular drop, Stork Stance Test, modified Star Excursion Balance Test, and Foot Posture Index were therefore compared within and between the groups using a Multivariate Repeated Measures ANOVA, which showed significant differences between groups for all outcomes of the intervention. The multivariate analysis revealed significant time group interaction effects (p = 0.000). Partial eta squared values for interaction effects for each variable are mentioned in Table 4. and indicate large effect sizes for all the variables. A p-value of 0.05 was regarded as significant for each test.

Table 2
Comparison of Parameters Within and Between the Groups

OUTCOME VARIABLES		Experimental GROUP A	Experimental GROUP B	Control GROUP C		
		Mean ± SD	Mean ± SD	Mean ± SD	P	F
Navicular Drop (mm)	Pre ND-R	14.11±2.91	15.11±3.14	15.77±3.00	0.305	
	Post ND-R	9.88±2.26	7.33±2.65	13.11±2.65	0.000*	958.2
	Pre ND-L	14.94±2.83	15.55±3.38	16.38±3.48	0.383	
	Post ND-L	10.58±2.73	8.44±2.59	13.55±3.01	0.000*	1153.0
Stork Stance Test (sec)	Pre SST-R	5.59±2.34	5.61±2.59	5.22±1.80	0.879	
	Post SST R	9.94±2.48	12.39±2.52	7.28±1.70	0.000*	350.5
	Pre SST-L	5.41±2.45	6.06±2.77	4.06±2.36	0.067	
	Post SST L	9.53±2.74	12.83±2.70	6.67±2.44	0.000*	428.8
Modified SEBT	Pre mSEBT R	231.96±17.0	232.71±16.6	233.51±17.6	0.204	
	Post mSEBT R	258.53±23.1	262.53±11.2	244.5±16.0	0.000*	503.6
	Pre mSEBT L	233.01±17.7	231.28±18.0	228.96±18.0	0.241	
	Post mSEBT L	256.51±21.0	264.94±17.1	235.53±16.9	0.000*	409.7
Foot Posture Index	Pre FPI-R	10.0±1.50	9.94±1.66	10.22±1.39	0.858	
	Post FPI R	6.35±1.11	4.11±1.18	8.22±1.43	0.000*	550.9
	Pre FPI-L	9.82±1.59	10.06±1.47	10.17±1.54	0.912	
	Post FPI L	6.53±1.06	4.33±.970	8.17±1.200	0.000*	565.2

Note. *Indicates significant difference in Post 4th week than pre-treatment with p<0.05; ND: Navicular Drop Test; SST: Stork Stance Test; mSEBT: modified Star Excursion Balance Test; FPI: Foot Posture Index; R: Right Foot; L: Left foot; SD: Standard Deviation.
Group A: Gluteus Max Strengthening + Short Foot Exercises.
Group B: Gluteus Med. Strengthening+ Short Foot Exercises.
Group C: Short Foot Exercises.

Table 3
Pairwise Mean Difference and Significance Value of Control Group and Experimental Groups (A & B)

OUTCOME VARIABLES	Control Group v/s Gluteus Maximus + SFE		Control Group v/s Gluteus Medius + SFE		Gmax+SFEv/s Gluteus medius + SFE	
	Mean Difference	P value	Mean Difference	P value	Mean Difference	P value
Post ND R	-2.44	0.029	-3.22	0.002*	0.77	0.679
Post ND L	-2.20	0.084	-2.97	0.002*	0.76	0.731
Post SST R	1.51	0.094	-2.75	0.001*	-1.24	0.201
Post SST L	2.11	0.038	4.08	0.000*	-1.97	0.055
Post mSEBT R	7.71	0.543	-1.49	0.001*	8.21	0.502
Post mSEBT L	8.82	0.452	2.94	0.001*	5.87	0.701
Post FPI R	-1.05	0.046	-2.19	0.000*	1.15	0.026
Post FPI L	-0.99	0.048	-1.97	0.000*	0.98	0.051

Note: *Indicates significant difference in Post 4th week than pre-treatment with p<0.05; ND: Navicular Drop Test; SST: Stork Stance Test; mSEBT: modified Star Excursion Balance Test; FPI: Foot Posture Index; R: Right Foot; L: Left foot; SD: Standard Deviation.
Group A: Gluteus Max Strengthening + Short Foot Exercises.
Group B: Gluteus Med. Strengthening+ Short Foot Exercises.
Group C: Short Foot Exercises.

Table 4
Partial Eta Square Values for all Outcome Variables for Significant Time*Group Interaction Effects

Outcome Parameters	*Partial Eta Squared Value (univariate)*
ND R	*.788*
ND L	*.764*
SST R	*.579*
SST L	*.561*
mSEBT R	*.810*
mSEBT L	*.799*
FPI R	*.654*
FPI L	*.670*

Note. ND: Navicular Drop Test; SST: Stork Stance Test; mSEBT: modified Star Excursion Balance Test; FPI: Foot Posture Index; R: Right Foot; L: Left foot.

Post hoc analysis (Tukey HSD, Multiple comparisons) revealed significant differences in Group A and C for ND R (p = 0.029), SST L (p = 0.038), FPI R (0.046) and FPI L (0.048). Also, significant differences were found between Group B and C for ND L (p = 0.012), SST R (p = 0.001), SST L (p = 0.000), FPI R (p = 0.000) and FPI L (p = 0.000). Furthermore, significant differences were observed between group A and B for FPI R (p = 0.026).

DISCUSSION

This study determined the effectiveness of Gluteus Maximus versus Gluteus Medius muscle strengthening on navicular drop, balance, and foot posture index among athletes with over-pronated feet. The findings of our current study suggested that there was an improvement in the navicular drop, Static Balance, and Dynamic Balance and Foot Posture shown by the navicular drop test, Stork Stance Test, modified Star Excursion Balance Test, and Foot Posture Index 6 with both – the conventional Short Foot Exercises program given to control group (Group C) and the Gluteus Medius Muscle strengthening program along with Short Foot Exercises to the experimental group (Group B) and the Gluteus Maximus Muscle strengthening program along with Short Foot Exercises to experimental (GROUP A).

Over the same period, however, the Group B intervention was more effective than the Group A and C interventions, with a greater reduction in navicular drop, significant improvement in Static and Dynamic Balance, and better foot posture and function in Group B subjects than in Group A and C subjects. According to Koh et al. (2013) hip external rotator weakness and dysfunction can cause hip adduction, medial rotation, and dynamic knee valgus, all of which can impair foot pronation. The gluteal muscles (maximus, medius, and minimus) stabilize the hip by counteracting gravity's hip adduction torque and maintaining proper leg alignment by eccentrically controlling thigh adduction and internal rotation and externally rotating lower extremity alignment, reducing foot pronation. Gluteal muscle weakness causes the hip joint to rotate internally and causes foot pronation. Reactivating the gluteal muscles will restore standard muscular recruitment patterns and improve gluteal muscle strength and performance. As a result, strengthening the gluteal muscles indirectly strengthens the kinetic chain and aids in the improvement of flat feet (Brijwasi &Borkar, 2023).

Previous research has linked neuromuscular alterations in the gluteus medius to ankle hypermobility, ankle injury, iliotibial band friction syndrome, and patellofemoral pain syndrome. Thus, strengthening the gluteus medius is advised to avoid and manage a variety of lower extremity dysfunctions caused by excessive pronation of the subtalar joint (Koh et al., 2013).

This study aimed to examine the effects of short foot workouts combined with gluteal muscle strengthening activities on overpronated feet. Gluteal muscles fight gravity's impact on hip adduction to keep the legs in the correct alignment and reduce foot pronation. They control thigh adduction, internal rotation, and external rotation at the lower extremity alignment (Goo et al., 2016). Engkananuwat et al. (2023) stated that insufficient gluteal muscles cause the hip joint to spin, which pronates the foot internally. Thus, by reactivating the gluteal muscles, correct recruitment patterns will be restored, the excessive medial shift of the weight-bearing line will be minimized, and foot pronation will be decreased. Indirectly strengthening the kinetic chain and reducing the incidence of flat feet improves hip and knee muscle function and strength (Engkananuwat et al., 2023). Strengthening the Gluteus Medius improves the ability of the intrinsic foot muscles to effectively support the medial longitudinal Arch (MLA), according to Choi et al. (2020). Like this study, Engkanauwat et al. (2023) found that performing Gluteus Medius exercises in addition to brief foot workouts increased navicular drop, arch height index, static balance, and dynamic balance more than performing foot muscle exercises alone.

According to Friel et al. (2006) and Negahban et al. (2013), hip weakness can lead to functional changes at the ankle (Friel et al., 2006; Hubbard et al., 2007). Friel et al. (2006) discovered a decline in hip abductor strength in Chronic Ankle Instability patients. Based on these findings, it has been proposed that hip abductors aid in keeping the hip abducted, hence minimizing foot pronation and avoiding ankle inversion. Kant et al. stated that the lower extremity is a serial linkage of multiple joints where the problem at one joint can be caused or corrected by compensation by the other joints Powers CM (2010). Foot moments during single leg stance can be influenced and compensated by hip abductor strength Friel (2006), Powers CM (2010).

The statistical analysis results supported the alternative hypothesis, demonstrating that gluteal muscle strengthening combined with short foot exercises is the most cost-effective and effective in reducing navicular drop, static and dynamic balance, and static and dynamic balance, thus improving foot posture and function.

CONCLUSION

The findings supported the primary hypothesis, revealing that a four-week gluteal muscle strengthening exercise program significantly improved foot posture and balance in athletes with over-pronated feet by reducing navicular drop. Furthermore, it was shown that gluteus medius muscle training combined with brief foot motions was more efficient than gluteus maximus muscle strengthening alone. As a result, this research shows that strengthening the gluteus medius muscle considerably influences over-pronated feet.

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Authors' contributions

All authors contributed in study design, statistical analysis and manuscript preparation.

Declaration of conflict interest

No conflict of interest is declared by the authors.

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