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Original Article

Influence of proximal hip muscle strengthening on medial longitudinal arch alignment: A randomized trial comparing gluteus maximus and gluteus medius exercises

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Abstract

Objective: To compare the effects of gluteus maximus (GMax) strengthening versus gluteus medius (GMed) strengthening on medial longitudinal arch (MLA) alignment in individuals with asymptomatic flexible flatfoot.

Methods: Fifty-three individuals with asymptomatic flexible flatfoot were randomly assigned to two groups for this randomized comparative study. GMax strengthening activities were assigned to Group A, and GMed exercises to Group B. For two weeks, both therapies were administered. The navicular drop test (NDT) and foot posture index (FPI), evaluated before and after the intervention, were among the outcome measures. SPSS version 26.0 was used for statistical analysis, and $p < 0.05$ was used for both within-group and between-group comparisons.

Results: After the intervention period, both groups showed statistically significant reductions in FPI scores and navicular decrease ($p < 0.05$). When comparing the GMed and GMax strengthening groups, the between-group analysis showed a considerably greater improvement in MLA alignment ($p < 0.05$). In individuals with asymptomatic flexible flatfoot, proximal hip muscle strengthening improves MLA alignment. The significance of focused hip abductor strengthening in the treatment of flexible flatfoot is evident, as GMed strengthening appears more successful than GMax strengthening in improving foot posture and reducing navicular drop.

Conclusion: Gluteus maximus and gluteus medius strengthening improved the medial longitudinal arch and foot posture in asymptomatic flexible flatfoot; however, gluteus medius strengthening was more effective, emphasizing the importance of hip abductor-focused protocols in physiotherapy.

Level of Evidence II; Randomized trial, Comparative study.

Keywords: Flexible flatfoot; Foot posture index; Navicular drop test; Gluteus medius; Gluteus maximus; Medial longitudinal arch.

Introduction

The medial longitudinal arch (MLA) of the foot plays an important role in shock absorption, weight distribution, and efficient gait mechanics. Flexible flatfoot, characterized by MLA collapse during weight-bearing that reappears in non-weight-bearing positions, is a common foot posture variation observed in both pediatric and adult populations[1]. Although often asymptomatic, flexible flatfoot has been associated with altered lower-limb biomechanics and may predispose individuals to future musculoskeletal disorders of the foot, ankle, knee, and hip[2].

Traditional rehabilitation approaches for flexible flatfoot have primarily focused on intrinsic foot muscle strengthening, orthotic support, and interventions targeting the ankle-foot complex. However, emerging evidence highlights the role of proximal segments of the kinetic chain in influencing distal

Study performed at the Datta Meghe College of Physiotherapy, Nagpur, Maharashtra, India.

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joint alignment and foot posture[3]. The concept of regional interdependence suggests that impairments at the hip can alter lower-limb kinematics, including excessive femoral internal rotation and adduction, which in turn may increase pronator forces at the subtalar joint and contribute to MLA collapse[4-6].

The gluteal muscle group, particularly the gluteus maximus (GMax) and gluteus medius (GMed), plays a critical role in controlling frontal- and transverse-plane movements of the lower limb. The GMed functions as a primary hip abductor and pelvic stabilizer during single-limb stance, while the GMax contributes significantly to hip extension and external rotation. Weakness or delayed activation of these muscles has been associated with increased dynamic knee valgus, excessive foot pronation, and altered plantar pressure distribution[7-9].

Despite growing interest in proximal strengthening strategies, there remains a paucity of comparative studies evaluating the differential effects of specific gluteal muscle strengthening on foot posture parameters[10]. Limited evidence exists comparing the influence of GMax versus GMed strengthening on MLA alignment in individuals with flexible flatfoot.

Therefore, the objective of this study is to evaluate and compare the effects of GMax and GMed strengthening exercises on MLA alignment in individuals with asymptomatic flexible flatfoot. It was hypothesized that proximal hip muscle strengthening would result in significant improvements in foot posture, with GMed strengthening demonstrating superior outcomes due to its critical role in frontal-plane pelvic and lower-limb stability.

Methods

The present study was conducted as a randomized comparative experimental trial to evaluate and compare the effects of proximal hip muscle strengthening on MLA alignment. The study was conducted in the Department of Physiotherapy at a tertiary-care teaching institute in Maharashtra, India. All assessments and interventions were conducted under the supervision of qualified physiotherapists. Before the trial started, the study was approved by the Institutional Review Board, and ethical guidelines were followed throughout.

Sample size was calculated using the following formula: $n = \frac{2(Z_{\frac{\alpha}{2}}+Z_\beta)^2}{d^2}$. Where, n = required sample size per group, $Z_{\frac{\alpha}{2}}$ = standard normal deviate for significance level α = 0.05 (1.96), Z_β = standard normal deviate for desired power of 80% (0.84), d = effect size (0.8), n = 24.5. Since sample sizes must be whole numbers, round up:, n = 25 per group, but to stay conservative and match software-based rounding (as done in Statsmodels), we use: n = 26 per group, the formula used for adjusted sample size (n_{adj}) is $n_{adj} = \frac{n}{1\text{-}Dropout\ rate}$ adjust for 10% dropouts, $n_{adj} = \frac{26}{1\text{-}0.10} = \frac{26}{0.90} = 28.89$, $n_{adj} =$ *29 participants per group*

After the study's methodology, potential benefits, and risks were outlined, each participant provided written informed consent.

A total of 70 participants diagnosed with asymptomatic flexible flatfoot were recruited for the study using a convenience sampling method as shown in Table 1. Participants were screened based on predefined inclusion and exclusion criteria. Individuals aged between 18 and 30 years with asymptomatic flexible flatfoot, positive navicular drop test (NDT), ability to understand and follow exercise instructions, and willing to participate and provide written informed consent. Excluded participants had a history of foot or ankle surgery, recent lower limb injury or trauma within the past six months, neurological disorders affecting gait or posture, structural or rigid flatfoot deformities, current use of foot orthoses or participation in any lower limb strengthening program.

Participants were randomly allocated into two groups using a computerized randomization method. Allocation was concealed in envelopes and single-assessor blinded to ensure equal distribution of participants between the groups: Group A (GMax Strengthening Group), 26 participants, and Group B (GMed Strengthening Group), 27 participants. Outcome measures were assessed at two points: baseline assessment and post-intervention (After two weeks). All measurements were taken by the same assessor to minimize inter-rater variability (Figure 1).

Outcome measures

The NDT was used to assess changes in the MLA height. The vertical distance of the navicular tuberosity from the floor was measured in a subtalar neutral non-weight-bearing position and then in a relaxed weight-bearing position. The difference between the two measurements was recorded in millimeters. Higher values indicated greater navicular drop and increased foot pronation[11].

Table 1. Interventional protocol

Group A (Gluteus Maximus strengthening)	Group B (Gluteus Medius strengthening)
Prone hip extension for a week, then progress with the TheraBand exercise	Progressive clamshell for a week, then progress with the TheraBand exercise
Common exercises for both groups (Figures 4E and 4F)	
Foot range of motion exercises (Figure 4A-D)	
Toe curls (Figure 4E)	
Foot gripping exercise (Figure 4F)	
Calf raises	
Quantity: 3 sets of 15 repetitions for 2 weeks, 12 sessions (6 per week)	Quantity: 3 sets of 15 repetitions for 2 weeks, 12 sessions (6 per week)

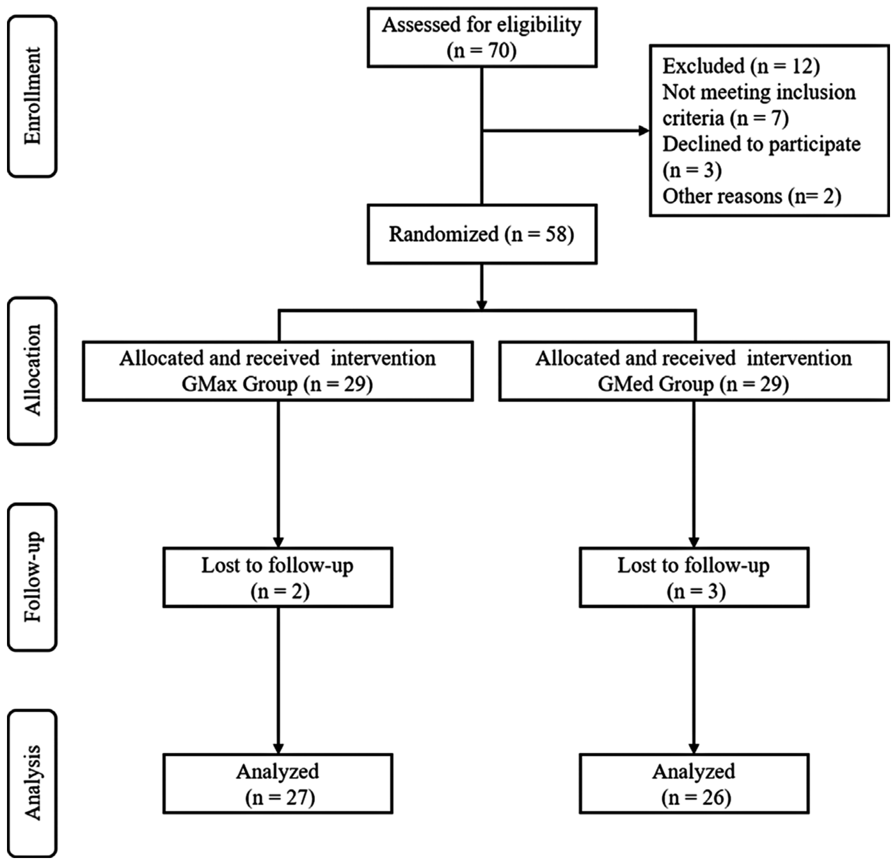

Figure 1. Randomized allocation process.

The foot posture index (FPI) was used to assess static foot posture. It consists of six criteria evaluating rearfoot and midfoot alignment in the sagittal, frontal, and transverse planes. The total scores range from -12 (extremely supinated) to +12 (strongly pronated), with each criterion being evaluated on a scale from -2 to +2. A more pronated foot position is indicated by higher scores[12].

Intervention protocol

Both groups underwent supervised exercise interventions for two weeks, with exercises performed five days per week as shown in Table 1. Each session lasted approximately 20-25 minutes.

Group A – GMax strengthening[13]

Participants in Group A performed exercises targeting the GMax muscle, including: Prone hip extension exercises progressing to resistance-based hip extension using Theraband. With suitable rest times in between sets, each exercise was performed in 2-3 sets of 10-15 repetitions, as shown in Figures 2A and 2B.

Group B – GMed strengthening

Participants in Group B performed exercises focusing on the GMed muscle, including: Clamshell, which was progressed after one week with Theraband. Each exercise was performed in 2-3 sets of 10-15 repetitions, with progression based on participant tolerance, as shown in Figures 3A and 3B.

Statistical analysis

Data were analyzed using IBM SPSS Statistics version 26.0. Descriptive statistics were calculated for demographic variables. The data normality was evaluated using the Shapiro-Wilk test. Paired t-tests were used for within-group comparisons, and independent samples t-tests were used for between-group comparisons. The statistical significance threshold was set at $p < 0.05$.

Results

A total of 53 individuals with asymptomatic flexible flatfoot successfully finished the research. Participants were randomly assigned to two groups: Group A (GMax strengthening, n = 26)

Figure 2. (A) Prone hip extension for Group A (B) Prone hip extension with Theraband for Group A.

Figure 3. (A) Clamshell exercise for Group B (B) Clamshell exercise with Theraband for Group B.

and Group B (GMed strengthening, n = 27). There were no statistically significant differences ($p > 0.05$) in baseline demographic characteristics (Table 2) and outcome indicators between the two groups, suggesting baseline homogeneity.

Table 2. Demographic data

Variables	Gluteus Maximus Group (n = 27) (mean ± standard deviation)	Gluteus Medius Group (n = 26) (mean ± standard deviation)	p-value
Age	23.37 ± 3.92	24.58 ± 3.46	0.24
Gender	1.55 ± 0.50	1.53 ± 0.50	0.90
BMI	24.75 ± 4.31	25.16 ± 5.09	0.78

BMI: Body mass index.

Within-group comparisons

Compared with baseline data (Table 3), individuals in Group A showed a statistically significant decrease in NDT scores after the two-week intervention, as shown in Figure 5A ($p < 0.05$). Furthermore, after the intervention, FPI scores significantly improved toward a more neutral foot posture as shown in Figure 5B ($p < 0.05$), indicating improved MLA alignment. Group B exhibited statistically significant improvements in both outcome measures following the intervention period, as shown in Table 4. Navicular drop values were significantly reduced post-intervention compared to baseline, as shown in Figure 6A ($p < 0.05$). Similarly, FPI scores demonstrated a significant shift toward neutral alignment, reflecting reduced foot pronation as shown in Figure 6B ($p < 0.05$).

Between-group comparisons

Between-group analysis revealed statistically significant differences (Table 5) in favor of Group B (GMed strengthening). The magnitude of reduction in NDT values was significantly greater in Group B compared to Group A ($p < 0.05$), as shown in Figure 7. Likewise, improvements in FPI scores were significantly greater in Group B (GMed strengthening) than Group A (GMax strengthening), as shown in Figure 8 ($p < 0.05$).

Discussion

The present study aimed to compare the effects of GMax and GMed strengthening on MLA alignment in individuals with asymptomatic flexible flatfoot. The findings demonstrated that although both intervention protocols resulted in significant improvements in navicular drop and FPI, GMed strengthening produced comparatively superior outcomes. These findings support the growing body of evidence suggesting that proximal muscle strength training can positively influence distal joint alignment through the interconnected kinetic chain of the lower extremity[3].

Table 3. Within-group analysis for Gluteus Maximus strengthening group

Outcome measure	Pre-test (mean ± standard deviation)	Post-test (mean ± standard deviation)	p-value
Navicular drop right (mm)	11.96 ± 1.37	10.37 ± 1.15	**<0.001***
Navicular drop left (mm)	12.22 ± 1.37	10.37 ± 1.21	**<0.001***
Foot posture index right side	7.48 ± 1.16	6.07 ± 1.30	**<0.001***
Foot posture index left side	7.30 ± 1.27	5.56 ± 1.37	**<0.001***

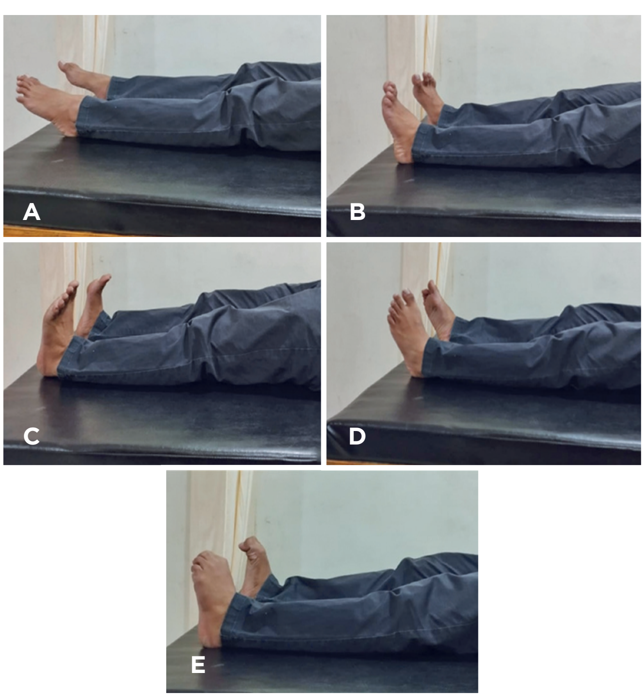

Figure 4. (A) Foot range of motion exercises—ankle plantarflexion (B) Foot range of motion exercises—ankle eversion (C) Foot range of motion exercises—ankle dorsiflexion (D) Foot range of motion exercises—ankle inversion (E) Toe curl exercise.

The biomechanical basis for proximal strengthening influencing foot posture can be explained by the concept of regional interdependence, wherein alterations at the hip affect kinematics at the knee and ankle due to the closed kinetic chain relationship of the lower limb[6]. Proximal hip muscle weakness, particularly of the gluteus muscle, has been associated with increased femoral internal rotation and adduction, leading to compensatory tibial internal rotation and excessive subtalar joint pronation[5]. These altered mechanics increase stress on the MLA, contributing to its collapse in individuals with flexible flatfoot. Recent literature has consistently demonstrated that proximal hip muscle strengthening can improve foot posture, medial arch height, balance, and functional outcomes by restoring optimal lower-limb alignment[3-9].

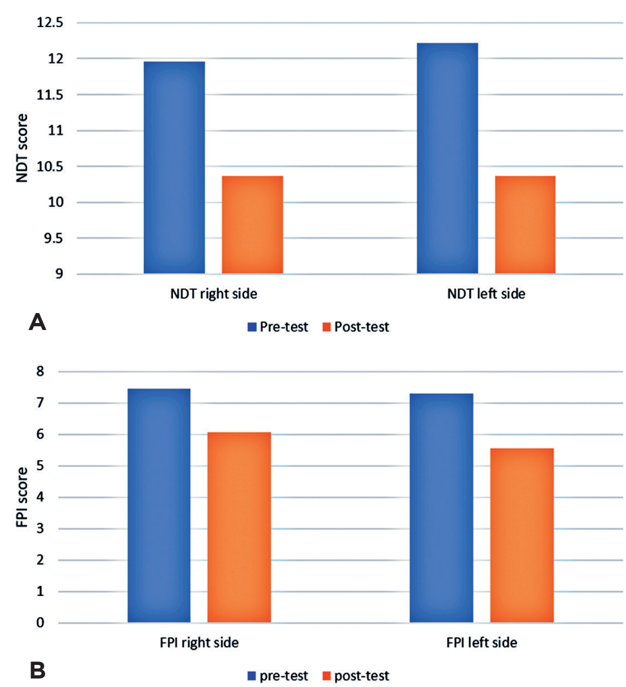

Figure 5. (A) Within-group analysis of NDT score for Group A (B) Within-group analysis of FPI score for Group A.

Table 4. Within-group analysis for Gluteus Medius strengthening group

Outcome measure	Pre-test (mean ± standard deviation)	Post-test (mean ± standard deviation)	p-value
Navicular drop right (mm)	12.00 ± 1.36	9.58 ± 1.30	**<0.001***
Navicular drop left (mm)	12.00 ± 1.30	9.65 ± 0.98	**<0.001***
Foot posture index right side	7.62 ± 1.24	4.77 ± 1.51	**<0.001***
Foot posture index left side	7.15 ± 1.32	4.46 ± 1.07	**<0.001***

Several studies within the last five years support the role of gluteal strengthening in improving MLA parameters. A randomized controlled trial by Engkananuwat and Kanlayanaphotporn (2023) demonstrated that a hip-strengthening program emphasizing the GMed resulted in significant reductions in navicular drop and improvements in foot posture compared to foot exercises alone, indicating the dominant influence of the hip abductors on foot alignment[8]. Similarly, Raghav et al. (2024)[9] reported that GMed strengthening combined with intrinsic foot muscle training led to greater improvements in FPI and balance compared to GMax-focused interventions, reinforcing the functional importance of the GMed in controlling pronation during weight-bearing tasks.

The superior effectiveness of GMed strengthening observed in the present study may also be explained by its functional role in daily activities. The GMed is highly active during walking, stair negotiation, single-limb stance, and postural stabilization, which are frequently performed activities in the 18-30-year age group included in this study[14]. In contrast, the GMax demonstrates peak activation primarily during high-intensity tasks such as jumping, sprinting, and landing, which may not be consistently engaged in routine daily activities[15]. As the participants in the present study were asymptomatic and physically active young adults, GMed strengthening likely

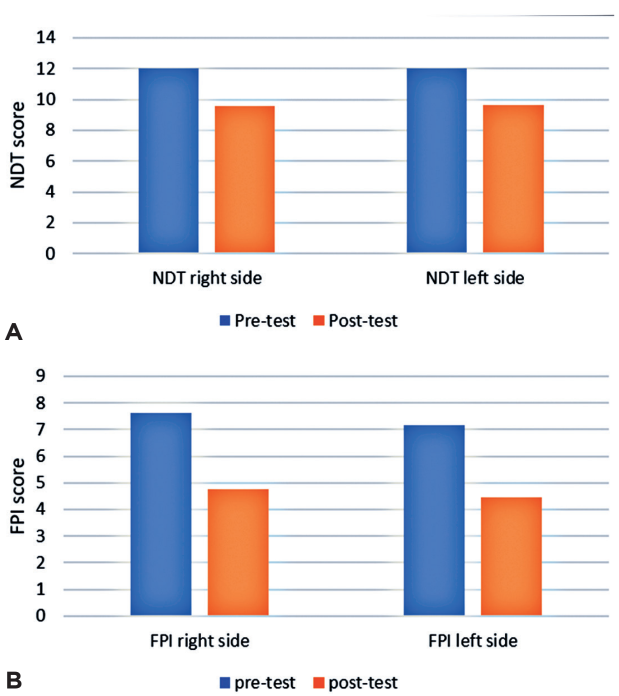

Figure 6. (A) Within-group analysis of NDT score for Group B (B) Within-group analysis of FPI score for Group B.

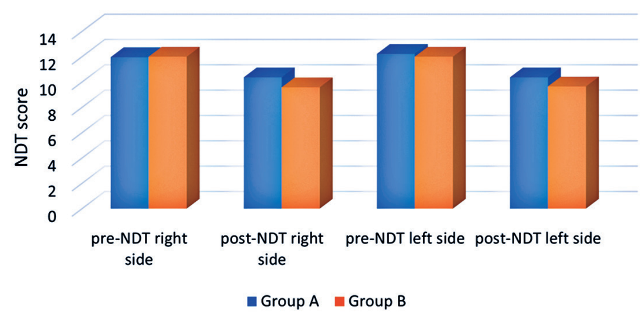

Figure 7. Post-test comparison between groups of NDT score.

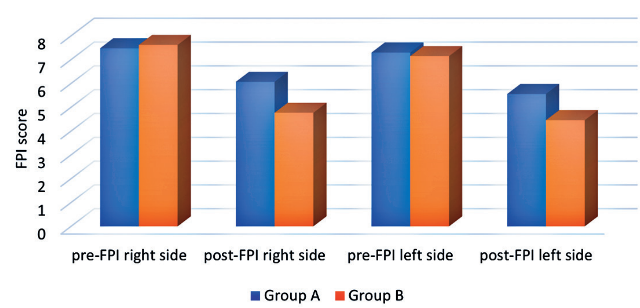

Figure 8. Post-test comparison between groups of FPI score.

Table 5. Within-group analysis for Gluteus Medius strengthening group

Outcome variable	Gluteus Maximus (Mean ± standard deviation)	Gluteus Medius (Mean ± standard deviation)	p-value	Effect size
Pre-intervention Navicular drop right side (mm)	11.96 ± 1.37	12 ± 1.36	0.922	-0.03
Post-intervention Navicular drop right side (mm)	10.37 ± 1.15	9.58 ± 1.30	**0.023***	0.64
Pre-intervention Navicular drop left side (mm)	12.22 ± 1.37	12 ± 1.30	0.547	0.16
Post-intervention Navicular drop left side (mm)	10.37 ± 1.21	9.65 ± 0.98	**0.026***	0.65
Pre-intervention Foot posture index right side	7.48 ± 1.16	7.62 ± 1.24	0.685	-0.12
Post-intervention Foot posture index right side	6.07 ± 1.30	4.77 ± 1.51	**0.001***	0.92
Pre-intervention Foot posture index left side	7.30 ± 1.27	7.15 ± 1.32	0.690	0.12
Post-intervention Foot posture index left side	5.56 ± 1.37	4.46 ± 1.07	**0.003***	0.89

Confidence interval = 95%, p-value ≤ 0.05* translated more directly into functional improvements during habitual weight-bearing activities, thereby producing greater changes in MLA alignment.

Another important factor contributing to the observed improvements over a short intervention period is the physiological phases of strength training[16]. Neuromuscular adaptations rather than muscle growth are primarily responsible for early strength improvements, especially during the first 2-3 weeks. Improved motor unit recruitment, synchronization, firing frequency, and neuromuscular coordination are among these changes[17]. These modifications lead to increased joint stability and muscle efficiency without appreciable increases in muscle cross-sectional area[18]. Improved neuromuscular control of the external rotators and hip abductors can quickly reduce abnormal lower-limb kinematics in the setting of flexible flatfoot, thereby reducing pronator loads at the foot and improving MLA alignment. This mechanism explains why significant improvements were seen in the current research within the comparatively brief 2-week intervention period.

The quick response to treatment may also be explained due to flexible flatfoot in the group under study is asymptomatic. The musculoskeletal system may have responded more effectively to corrective strengthening exercises since these people did not have long-standing neuromuscular deficits, structural deformities, or persistent discomfort. Additionally, because short-duration intervention techniques increase exercise program adherence and lower dropout rates, they may be especially beneficial in asymptomatic individuals. The need for ongoing or progressive strengthening programs to sustain long-term benefits is highlighted because neuromuscular changes from short-term training may be temporary and reversible if activity is reduced[19].

The lack of a nonintervention control group in the current investigation was a crucial methodological factor. Rather than comparing the efficacy of exercise with no therapy, the main goal was to examine the relative efficacy of two active strengthening regimens. Additionally, the study population consisted of young adults enrolled in college, and it was thought to be difficult to recruit and retain participants in a nontreatment control group because of their academic obligations and decreased motivation to participate in the absence of an intervention.

The fact that both intervention groups were given a similar program of intrinsic foot exercises, such as calf lifts, foot curls, foot rolling, and active range of motion exercises, is crucial to consider when evaluating the current results. By increasing intrinsic foot muscle activation and arch stiffness, these workouts can independently enhance medial longitudinal arch height and foot posture, according to prior research. Therefore, rather than only hip-strengthening therapies, these common exercises may have contributed to some of the improvement shown in both groups. However, given the foot training regimen was the same for both groups, the GMed group's better results suggest an additional advantage of focused GMed strengthening.

On the other hand, even though GMax strengthening produced notable gains, its primary role in sagittal-plane movement and high-force exercises may explain its relatively smaller impact on MLA alignment[14]. Compared with the GMed, enhanced GMax strength had less impact on sustained frontal-plane control during single-limb stance, even though it does contribute to total lower-limb stability and propulsion. The results of the current study are further supported by a randomized trial by Aiswarya et al. (2024)[20], which showed that hip abductor-focused training produced superior improvements in alignment-related outcomes while GMax strengthening improved lower-limb power and functional performance.

According to this study, young individuals with asymptomatic flexible flatfoot may benefit greatly from proximal hip strengthening, specifically targeting the GMed, to improve MLA alignment. The amount of improvement seen in this trial seems to be clinically significant beyond statistical significance. Participants in the GMed group showed a discernible shift toward a less pronated foot posture, with a mean decrease of almost 2.4 mm in navicular drop and nearly 3 points on FPI scores. The mechanical efficiency of the foot during weight-bearing activities may be enhanced by even small improvements in medial longitudinal arch alignment, which may decrease excessive strain on the tibialis posterior tendon, spring ligament, and plantar fascia. Such modifications are especially crucial in asymptomatic people, as the aim of the intervention is prevention rather than symptom alleviation. Plantar fasciitis, patellofemoral pain syndrome, shin splints, and progressive collapsing foot deformity are among the problems that may be prevented in the future by improving early foot posture and reducing cumulative biomechanical stress across the lower kinetic chain. As a result, in addition to being statistically significant, the gains seen may also be clinically important adaptations that promote long-term musculoskeletal health and injury prevention.

The results support the use of short-term, functionally appropriate exercise regimens to improve adherence and early biomechanical rectification and highlight the need to integrate proximal strengthening techniques into flatfoot care procedures.

This study has several limitations that should be considered when interpreting the findings. First, the absence of a nonintervention or foot-exercise-only control group limits the ability to determine whether the observed improvements were solely attributable to GMax or GMed strengthening. Since both groups performed the same intrinsic foot exercise program, improvements in medial longitudinal arch measures may have been partially influenced by these common exercises. Second, the intervention and follow-up period were limited to two weeks, preventing evaluation of the long-term sustainability of the observed changes and whether these improvements persist after cessation of training.

Third, the sample consisted exclusively of young adults with asymptomatic flexible flatfoot, which restricts the generalizability of the findings to symptomatic individuals, pediatric populations, older adults, or athletes with higher functional demands. Fourth, outcome measures were limited to static assessments and therefore did not capture dynamic biomechanical adaptations during gait or functional activities

A limitation of the present study was the absence of a non-intervention control group. The primary objective was to compare the effectiveness of two active strengthening interventions rather than to evaluate exercise against no treatment. Furthermore, the study population consisted of college-going young adults, making recruitment and retention of participants in a no-treatment group challenging due to academic commitments and reduced willingness to participate without receiving an intervention.

Conclusion

Gluteus maximus and gluteus medius strengthening improved the medial longitudinal arch and foot posture in asymptomatic flexible flatfoot; however, gluteus medius strengthening was more effective, emphasizing the importance of hip abductor-focused protocols in physiotherapy.

Authors' contributions: Each author contributed individually and significantly to the development of this article: RA *(https://orcid.org/0000-0001-9012-3933) Conceived and planned the activities that led to the study, and wrote the paper; ND *(https://orcid.org/0009-0008-2599-487X) Interpreted the results, participated in reviewing and finalising the manuscript; MK *(https://orcid.org/0000-0001-6781-8446), MS *(https://orcid.org/0000-0001-7416-4663), and AB *(https://orcid.org/0009-0008-3256-9409) Participated in reviewing process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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