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Effect of Toe Walking Exercises and Intrinsic Foot Muscle Exercises for Individuals With Flat Foot: A Comparative Study

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SUMMARY

Background and aim. Human feet possess a unique arched structure that distributes forces efficiently during movement. This stability relies on interplay between muscles and tendons. Flat feet (pes planus) are a common condition, yet its historical development remains poorly understood. This study addresses this gap by comparing two existing interventions for pes planus: toe walking exercises and intrinsic foot exercises.
Methods. This study involves 40 flat-footed individuals who were selected based on the inclusion and exclusion criteria. The foot posture index (FPI-6) is used to analyze the posture of the flat foot and the navicular drop index (NDI) to observe the changes in the navicular drop before and after the exercises. The subjects were divided into two groups, the first group (n = 20) was prescribed toe walking exercises, and the second group (n = 20) was given intrinsic foot muscle exercises.
Results. The analysis revealed a statistically significant difference (P-value < 0.0001) in favor of the intrinsic foot muscle exercise group. This indicates that individuals in this group experienced a greater improvement in their flat feet compared to those in the toe walking group.
Conclusions. It is suggested that intrinsic foot muscle exercises can be more effective and show greater changes in navicular drop for individuals with flat feet.

KEY WORDS

Flat foot; intrinsic foot muscle exercise; toe walking; plantar fascia; pes planus.

INTRODUCTION

The lower medial longitudinal arch (MLA) with calcaneal eversion is a characteristic of the common chronic ailment known as pes planus, which has a reported incidence of 2% to 23% in the adult population (1).

The most common cause of pes planus is excessive pronation during weight-bearing workouts. In addition to increased stress on the ankle, foot, and knee joints and an internal rotation of the hip as a coping strategy, pes planus causes incorrect plantar load distribution. Pes planus is also associated with numerous ailments of the lower limb, including tarsal tunnel syndrome, hallux valgus, plantar fasciitis, dysfunction of the tibialis posterior, and patellofemoral pain syndrome (2).

Pes planus, sometimes referred to as “flatfoot” or “fallen arches,” is a medical condition that causes the medial longitudinal arch (MLA), which runs the whole length of the foot, to become depressed or flattened. A flat foot can affect one or both feet, putting additional pressure on the foot structure and impairing typical foot functioning. Consequently, people with flat feet find it uncomfortable to stand for extended periods of time, and their gait is clearly recognized. Plantar fascia soreness, loosened ligaments, fast foot fatigue, and instability on the medial side of the foot under load are prominent signs of flat feet (3).

Flatfoot has been associated with a wide range of medical disorders, including lower limb musculoskeletal diseases such as plantar fasciitis. The flattening MLA gradually causes proximal mechanical overloading in the lower back, hips, and knees. Overpronation happens in the standing phase of the gait (4).

Consequently, impaired dynamic function and associated foot malformations result in an aberrant pattern of plantar pressure in the pes planus. For the foot to perform its roles of shock absorption, body weight transmission, and acting as a lever to drive the body forward during locomotion, it must have both structure and dynamicity (5).

The greater than the lateral longitudinal arch is the medial longitudinal arch (MLA) of the foot and when one bears weight, its curvature flattens to varying degrees. A medical ailment known as pes planus occurs when the MLA curvature is more flat than usual, and the entire foot sole makes full or nearly complete contact with the earth. The most crucial measurement in figuring out the degree of pes planus is the height of the MLA. Because of their fat, newborns' feet appear to be flat. The child's arches become more noticeable when they begin to walk, and their foot begins to bear weight. Between two and six years old, the foot arches grow quickly, and between the ages of twelve and thirteen, they reach structural maturity. Because of ligament laxity, flat feet are more common in children and become less common as people age (6). Children's early shoe usage hinders the development of longitudinal arches.

The deformation of the arches on the inside of the foot, commonly referred to as flat foot or pes planus, is a common ailment. The two general categories for this anatomical variation are rigid flat foot, in which the arch remains flattened in both non-weight-bearing and weight-bearing situations, and flexible flat foot, in which the arch is present when non-weight-bearing but collapses with weight-bearing. Aching, weariness, or pain in the feet can be felt by some people with flat feet, especially after extended periods of standing or physical activity (7, 8).

Factors contributing to flat feet include genetics, aging, injury, or conditions such as tendon dysfunction. A flat foot can impact the alignment of the lower extremities and may lead to issues such as overpronation, which can affect the ankles, knees, and even the lower back. Management strategies for flat feet often involve supportive footwear, orthotic inserts, and exercises aimed at strengthening the foot and ankle muscles (9). In severe cases or when associated with significant symptoms, medical intervention, surgeries, or physical therapy, for example, may be considered to address the underlying structural issues and improve foot function. It's crucial for individuals experiencing discomfort or functional limitations associated with flat feet to seek professional advice for an accurate diagnosis and appropriate management.

Harris RT and Beath T divided flat foot deformity into three subtypes. There are three types of flat feet: stiff, flexible, and flexible with short tendon Achilles (FFF-STA). FFF often has no symptoms, however, FFF-STA can cause discomfort and functional impairment. Reduced range of motion at the subtalar joint and tarsal coalitions are linked to a rigid flat foot, which is frequently symptomatic (10). There are concerns regarding the actual prevalence of flat feet because there are no clear clinical or radiographic standards for identifying the condition. Numerous academics from around the globe have investigated the phenomenon of flat feet. Primary school pupils have a lower prevalence (13.4% to 27.6%), while children between the ages of two and six have a higher incidence (21 to 57%). According to the findings of several researchers, the adult population's share falls between 5 and 14%. The frequency of adult flat feet in Indian populations has not been thoroughly studied, and when it has, the methods employed are unclear (11).

An average gait cycle divides its stance phase and swing phase according to the degree to which each limb is impacted. Beginning with the heel strike and ending with the toe-off, the stance phase is where the weight is carried during the cycle. It further divides into three divisions: flat foot (mid and terminal stance), heel strike, and heel raise. A person walking normally starts the weight-bearing portion of their limb at the first heel strike. Tibia inward rotation and plantar flexion of the ankle joint are brought about by the calcaneocuboid, talonavicular, and subtalar triple joint complex, which regulates foot version and arch collapse. Acting as an eccentric shock absorber, the posterior tibialis muscle (12). The cuboid is led into this everted position by the calcaneus, which flattens the medial longitudinal arch and abducts the forefoot. Rather than contracting concentrically, the anterior crural compartment muscles contract eccentrically in response to the ground-reaction force caused by heel strikes (13).

This eccentric contraction keeps the foot from slapping down during the heel strike, which gives control and cushioning as the foot gets closer to the mid-stance or flat foot phase of stride. The anterior and posterior crural muscles' eccentric control over the ankle and hindfoot reduces the force of weight bearing when the foot moves from heel strike to flat foot. The foot's weight centers at the level of the second metatarsal during the gait cycle's flat foot mid-stance phase. The tibia rotates outward and the ankle dorsiflexes as the body's center of gravity shifts forward over the foot and towards the heel rise.

By reconstituting the medial collateral ligament, the medial column becomes a stiff lever when the posture is slightly varus. The push-off portion of gait propulsion is then accomplished with the stiff lever. Because of its intricate movement and function, the foot has two distinct arch shapes: a rigid arch that may be reconfigured to provide efficient walking propulsion, and a medial arch that can partially collapse to reduce the force of weight bearing. Function comes before form. We can now run, jump, climb, and stroll across uneven ground because of this. There are various possible causes of this intricate biomechanical mechanism going wrong. With the pull of the PTT, the hindfoot or triple joint complex actively inverts and adopts a mild varus posture (14).

The foot may be an amazing, versatile, and strong instrument for sprinting, jumping, walking, and traveling over uneven

ground and slopes when it is functioning properly. The foot may become malformed and become dysfunctional if it is no longer supported by its normal structure. An imbalance between the forces that seek to sustain and flatten the arch might lead to the loss of the medial longitudinal arch (15).
A gain in body weight or an increase in the triceps suras's ability to flatten the arch will usually cause the arch to become flatter. If the supporting muscles, ligaments, or bones are weak, the arch will collapse. Adults with acquired flat feet typically have difficult therapy (16, 17). The therapist should consider the biomechanics of the normal arch when implementing a treatment plan that strengthens the arch's supporting components or reduces its tendency to flatten (18). After osteotomies or other procedures, the PTT and other arch-supporting muscles are less crucial for preserving the arch. Improving function and reducing the likelihood of future deformity development can be achieved by rebalancing the forces acting on the arch (18).

MATERIALS AND METHODS

Participants

Forty volunteers aged 18-25 with confirmed flat feet, diagnosed using the Foot Posture Index-6 (FPI-6), participated in this comparative study. After providing written informed consent, participants were randomly divided into two groups (n = 20 per group): a toe walking exercise group and an intrinsic foot muscle exercise group. The study procedures were explained in detail to all participants. Pre- and post-intervention assessments were conducted using the Navicular Drop Index (NDI) and Foot Posture Index (FPI).

Ethical approval

The approval was taken from the Saveetha College of Physiotherapy Institutional Ethical Commitee with Institutional Scientific Review Board Number: 04/013/2023/ISRB/SR/SCPT - date of approval: December 23, 2023.

Sample size justification

A sample size of 40 participants (20 per group) was chosen based on previous research investigating the effects of exercise interventions on flat feet. This sample size was determined to provide adequate statistical power to detect significant differences between the exercise groups.

Exercise interventions

Toe Walking Exercise Group

Participants in this group practiced toe walking with gradually increasing durations and repetitions (starting with 3 sets of 30 seconds to 1 minute) as their strength and endurance improved. They maintained a "ballet-like" posture, lifting their heels while taking deliberate steps forward with feet hip-width apart. Variations were progressively introduced, including walking on inclines, holding light weights, and even single-leg toe walking.

Intrinsic Foot Muscle Exercise Group

This group performed a variety of exercises targeting the intrinsic foot muscles:

1. Toe Spreading: participants seated comfortably spread their toes as wide as possible, holding the pose for a few seconds before relaxing and repeating (2-3 sets of 10-15 repetitions).
2. Toe Flexor Stretch: while seated, participants held one foot crossed over the opposite knee and gently pulled the toes backward, holding the stretch for 15-30 seconds before switching sides (2-3 sets per foot).
3. Toe Tapping: standing with feet flat, participants lifted one foot, keeping the heel on the ground, and tapped the toes repeatedly (continued for 1-2 minutes, gradually increasing duration).
4. Marble Pick-Up: seated comfortably, participants used their toes to pick up marbles or small objects from the floor, repeating until all objects were collected (performed up to 2-3 sets).
5. Short Foot Exercise: seated with feet flat, participants "shortened" their feet by engaging the muscles under the arch, holding for 5-10 seconds before relaxing (repeated for 2-3 sets of 10 repetitions).
6. Toe Curls: standing with a towel placed under their feet, participants curled their toes to grab the towel, holding for 5-10 seconds before releasing (repeated for 2-3 sets of 10 repetitions).
7. Intrinsic Muscle Strengthening with Resistance Band: participants wrapped a resistance band around their toes and performed toe extension and flexion exercises against the resistance (2-3 sets of 10-15 repetitions per foot).
8. Rolling: as part of the pre-intervention assessment, participants underwent a plantar massage by rolling a ball under their feet for 5-10 minutes per foot.

Outcome measure

Navicular drop index

A straightforward and well-liked clinical method for determining the extent of pes planus, or flat feet, is the navicular drop test. It measures how much the navicular tuberosity moves vertically from a neutral subtalar posture to a comfortable standing position. Interpretation less than a

10-millimeter navicular dip is regarded as usual. A 10 to 15 mm navicular dip is regarded as mild pes planus. The definition of a mild case of pes planus is a 15-20 mm navicular depression. When the navicular drop is more than 20 mm, it is referred to as severe pes planus.

Foot posture index (FPI-6)

The Foot Posture Index 6 (FPI-6) is a reliable and valid tool for quickly and easily assessing standing foot posture. In clinical settings and research investigations, it is widely used to assess the severity of flat feet (pes planus) and monitor changes over time. Each component is given a number between 0 and 3, where 0 represents the average foot structure and 3 represents a significant deviation. The scores for each of the six components are then added to determine the overall FPI-6 score, which goes from 0 to 18.

Vernier caliper

This study utilizes a digital vernier caliper to measure the NDI. A vernier caliper employs two scales for measurement: a fixed main scale with millimeter readings and a movable vernier scale. The vernier scale, with a length of 9 mm, is divided into 10 sections. Notably, each vernier scale division measures 0.9 mm, which is 0.1 mm shorter than the main scale divisions.

Statistical analysis

To assess the intervention's effect, we (same authors) employed paired t-tests to compare pre- and post-intervention scores within each exercise group (toe walking and intrinsic foot muscle). Independent t-tests were then used to evaluate the post-intervention means between the two groups for both the Navicular Drop Index (NDI) and Foot Posture Index (FPI) scores. A P-value of less than 0.0001 was set as the threshold for statistical significance.

RESULTS

Both the toe walking and intrinsic foot muscle exercise groups exhibited statistically significant improvements in NDI scores following the intervention period ($p < 0.0001$). However, the intrinsic foot muscle exercise group demonstrated a greater improvement compared to the toe walking group, with a significantly lower post-intervention mean NDI score (t = [test statistic value], $p < 0.0001$).

Toe Walking Exercise Group: pre-intervention NDI (mean ± SD) = 15.770 ± 2.91, post-intervention (mean ± SD) = 15.50 ± 2.930 (t = 15.77, $p < 0.0001$) as shown in **table I** and **figure 1**.

Intrinsic Foot Muscle Exercise Group: pre-intervention NDI (mean ± SD) = 15.680 ± 2.59, post-intervention (mean ± SD) = 12.62 ± 2.59 (t = 12.28, $p < 0.0001$) as shown in **table II** and **figure 2**.

Post-intervention comparison: Toe Walking *vs* Intrinsic Foot Muscle: post-intervention (mean ± SD) = 15.50 ± 2.93, post-intervention (mean ± SD) = 12.62 ± 2.59 (t = [test statistic value], $p < 0.0001$) as both of them were compared and shown in **table III** and **figure 3**.

Table I. Comparison of pre- and post-value of toe walking exercise group using NDI by paired t-test.

Statistical analysis	Pre-test	Post-test	T-value	P-value
Mean	15.770	15.505		
SD	2.914	2.930	15.770	< 0.0001
SEM	0.652	0.655		

Table II. Comparison of pre- and post-value of intrinsic foot muscle exercise group using NDI by paired t-test.

Statistical analysis	Pre-test	Post-test	T-value	P-value
Mean	15.680	12.625		
SD	2.595	2.210	12.289	< 0.0001
SEM	0.580	0.484		

Table III. Comparison of post-test value NDI of toe walking exercise group and intrinsic foot muscle exercise group by using unpaired t-test.

Statistical analysis	Toe walking exercise	Intrinsic foot muscle exercise	T-value	P-value
Mean	15.505	12.825		
SD	2.929	2.209	3.26	< 0.0023
SEM	0.655	0.494		

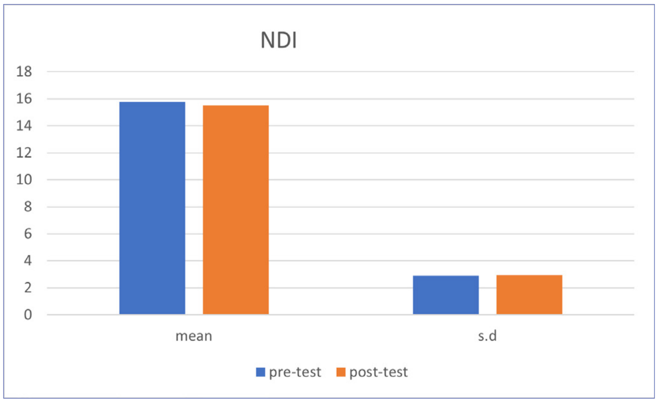

Figure 1. The pre-test and post-test value of toe walking exercise using NDT by paired t-test.

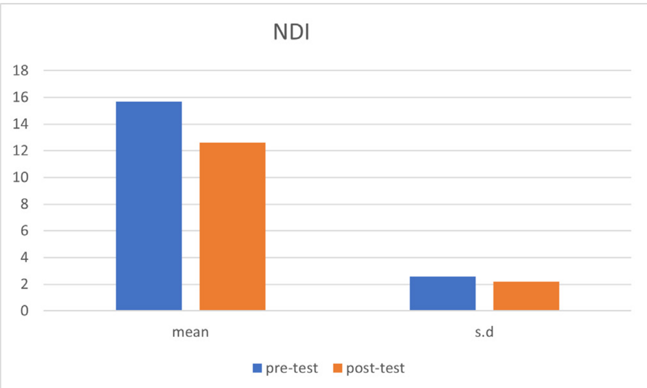

Figure 2. The pre-test and post-test value of intrinsic foot muscle exercises using NDT.

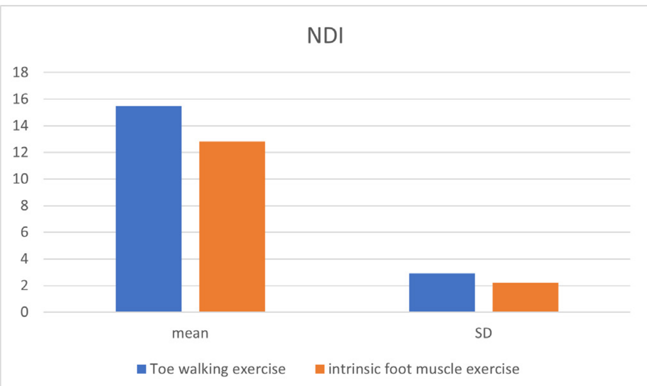

Figure 3. The post-test value of toe walking exercise group and intrinsic foot muscle exercises group using unpaired t-test.

DISCUSSION

The purpose of this study is to compare the benefits of toe walking exercises with those that focus on the intrinsic foot muscles. Participants in the study were chosen according to their foot posture index scores, which were 8-9 for strongly pronated feet and 6-7 for mildly pronated feet. The contrast is demonstrated over eight weeks. The outcomes were assessed both before and after the therapy using the navicular drop index and the foot posture index.

This study investigated the effectiveness of toe walking exercises compared to intrinsic foot muscle exercises for individuals with flat feet (pes planus). Participants were recruited based on their Foot Posture Index (FPI) scores, targeting individuals with moderate to severe flat feet (FPI 6-9). The results demonstrated that the intrinsic foot muscle exercise group achieved significantly greater improvement in the Navicular Drop Index (NDI) compared to the toe walking group. This section will delve into the potential reasons behind these findings by examining the distinct mechanisms of each exercise type and incorporating insights from relevant literature.

The observed difference in effectiveness likely stems from the way these interventions target the foot musculature. Toe walking primarily engages the plantar flexor muscles on the underside of the foot and the calf muscles in the lower leg (8). While strengthening these muscles is beneficial for overall leg strength and stability, it may not directly address the underlying weakness or imbalance in the intrinsic foot muscles. These intrinsic foot muscles, as detailed by McKeon *et al.* (8), form the "foot core system" and play a crucial role in maintaining the medial longitudinal arch during weight-bearing activities like walking. Studies by Brijwasi and Borkar (15) further support this notion, demonstrating that individuals with flat feet often exhibit weakness in these intrinsic muscles.

On the other hand, intrinsic foot muscle exercises specifically target these small muscles within the arch of the foot. These exercises, as explored by Newsham (9), can involve various techniques to activate and strengthen the intrinsic foot muscles. By directly addressing this musculature, the intrinsic foot muscle exercises in our study may have more effectively counteracted the biomechanical dysfunction associated with flat feet, as observed in the improved NDI scores (10).

This study's findings also shed light on the potential role of hypermobility of the first ray (the big toe segment) in flat feet. Studies by Kim and Kim (11) suggest that short foot exercises, which share similarities with intrinsic foot muscle exercises, can improve the medial longitudinal arch in individuals with flexible flatfoot. This improvement may be linked to better control of the first ray during walking and potentially a more efficient windlass effect. The windlass effect, as described by Haun *et al.* (12), refers to the mechanism by which the plantar fascia, a ligament on the sole of the foot, tightens and supports the arch during foot strike. Intrinsic foot muscle exercises, by strengthening the muscles that control the first ray and the arch (13), may help to improve this windlass effect and contribute to a more stable and functional foot posture. This improved windlass effect could explain the greater improvement in NDI scores observed in the intrinsic foot muscle exercise group compared to the toe walking group. A growing body of research supports the effectiveness of intrinsic foot muscle exercises for flat feet. A recent review by Hara *et al.* highlights the potential of short foot exercises targeting similar musculature as intrinsic foot muscle exercises to treat flat foot deformity (1). Additionally, studies by Moon and Jung (17) and Brijwasi and Borkar (15) demonstrate the positive impact of exercise programs that incorporate intrinsic foot muscle strengthening on balance and foot alignment in individuals with flat feet. These findings align with our study's results, suggesting that intrinsic foot muscle exercises are a valuable strategy for managing flat feet and improving NDI scores. While the toe walking strengthens some leg muscles, research by Kerrigan *et al.* suggests it may not directly address the underlying weakness in the ankle and foot muscles crucial for maintaining arch stability during walking. This could explain our study's observed lower effectiveness of toe walking exercises compared to intrinsic foot muscle exercises (19). Toe walking primarily strengthens the plantar flexors and calf muscles, which are less directly involved in maintaining the medial longitudinal arch during gait compared to the intrinsic foot muscles. This study has limitations. The sample size was relatively small, and further research with larger populations is warranted. Additionally, long-term follow-up studies are needed to determine the sustainability of the observed improvements in NDI scores. Future research directions could explore the optimal dosage and duration of intrinsic foot muscle exercise programs for flat feet. Investigating the combined effects of intrinsic foot muscle exercises with other interventions like arch support insoles, as explored by Kim and Kim (11), could also be of interest. Studies like Nielsen *et al*. (18) found that foot length and gender, but not age or BMI, significantly influence navicular drop during walking. The authors developed linear models to calculate normal values for navicular drop based on foot length and gender. These models can be used to improve the accuracy of diagnosing foot disorders.

CONCLUSIONS

According to the study's findings, people with flat feet can benefit from toe walking exercise; however, intrinsic foot muscle activity appears to be more beneficial and has a minor positive impact on the navicular drop test.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

HS: writing - original draft, data curation, investigation. SS: conceptualization, project administration. NP, BM, JJ: resources.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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