# Effects of Foot Intrinsic Strengthening of Pes Planus Children on Foot Morphology and Gait

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***Purpose*** The purpose of this study was to investigate the effects of strengthening intrinsic foot muscle on foot morphology and gait in pes planus children with developmental delay. ***Methods*** Eighteen participants were randomly assigned to the study and control groups. Each group underwent the respective intervention for eight weeks, two times a week, 30 minutes per session. Arch height index was measured to assess foot morphology, gait ability was assessed using temporal distance gait analysis. ***Results*** Arch height index was not significantly increased in both the study and control groups ($p>.05$). In the temporal distance gait analysis, the study group showed significantly improved stride length post-intervention ($p<.05$). Additionally, the study group showed a significant improvement in the number of steps after the intervention compared with the control group ($p<.05$). ***Conclusion*** Strengthening intrinsic foot muscles is effective in improving the foot morphology and gait ability of pes planus children with developmental delays compared with conventional physical therapy using orthosis and insoles.

***Key Words*** Arch height index, Delayed development, Gait analysis, Intrinsic foot muscles, Pes planus

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## Ⅰ. Introduction

Delayed development refers to a case in which a delay in physical and mental development exists due to a delay in one or more of the four areas, including motor, cognitive, emotional, and social skills, and language[1)] covers a wide range of diseases. In general, there are mental retardation, cerebral palsy, autism disorder, developmental language disorder and special sensory dysfunction such as vision and hearing, learning disorder, attention deficit, and hyperactivity disorder, are present.[2)]

The foot plays various roles in providing postural control through sensory information coming into the sole.[3)] Children's feet are vulnerable to deformation as children have a growing musculoskeletal system and are affected by congenital or external factors.[4)] Children with developmental delays in intellectual and motor skills exhibit excessive joint flexibility, hypotonia, and muscle weakness.[5)] Pes planus in children is associated with obesity, joint and ligament laxity, muscle weakness, and weakness of the posterior tibialis tendon.[6)] Males, obesity, and younger age were more closely related to risk factors than females in preterm children.[7)] The prevalence of pes planus in school-aged children varies from 12 to 45.5%, however, the rate of pes planus is 1.5 times higher than that of children with normal development in the case of children with developmental delay.[8)] Pes planus can lead to abnormal gait or motor dysfunction,[9)] and are linked to abnormal biomechanics of the lower limbs, which increase the risk of damage from continuous overuse.[10)]

Some studies have applied active strengthening exercises to adults with pes planus or passive intervention methods to children. However, studies that have performed active methods in children are lacking. Therefore, in this study, we compared the

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study group in which intrinsic muscle strengthening was performed using a footrest from which support was removed in the middle of the foot and the control group who performed conventional physical therapy by wearing an orthosis or insole providing support in the middle of the foot. This study aimed to investigate the effect of muscle strengthening on foot morphology and gait ability.

## II. Materials and Methods

### 1. Subjects

1) This study was approved by the Institutional Review Board of Yongin University (approval number: 2206-HSR-262-2). Eighteen children with developmental delays at B Hospital in Yongin were classified into a study group (n=9) that received foot intrinsic muscle strengthening intervention and a control group (n=9) that received conventional physical therapy. The intervention program was applied 30 minutes, twice a week for a total of 8 weeks during the study period (Figure 1). Subject selection conditions are as follows

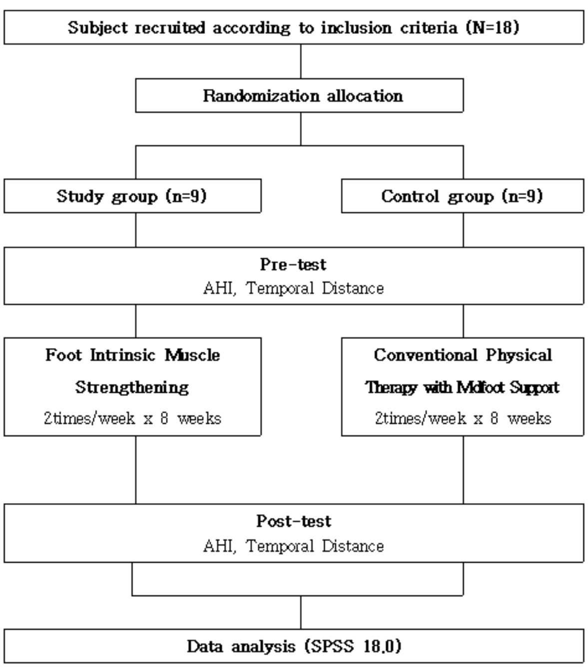


**Figure 1. Schematic diagram of the study**
**Note. AHI: Arch Height Index**

#### 2) Selection Criteria

First, children diagnosed with developmental delay by medical institutions.

Second, children with grade 1 or higher on podoscope examination and children with no change in the examination results for 1 year.

Third, children who can follow instructions.

Fourth, children who have been walking independently for more than 1 year.

#### 3) Exclusion Criteria

First, children who can not follow instructions.

Second, children who have spasticity over MAS 1 on lower extremities.

### 2. Intervention

#### 1) Foot intrinsic muscles strengthening

This study program proceeded with strengthening the intrinsic muscles using a footrest with the midfoot removed based on the short-foot exercises suggested in previous studies.[11,12] It starts with the children in a sitting position with the pelvis and trunk upright on a treatment table.

##### (1) Increasing foot awareness

This phase provides mobility to subtalar joint and joints that make up the metatarsal joints in the sitting position on the treatment table. An elastic band was used to induce the elevation of the medial longitudinal arch (Figure 2A). The first metatarsophalangeal joint was then induced to flex, and a short foot exercise was performed (Figure 2B). Subsequently, centering on the toe on the ground, the tension of the plantar fascia is increased by lifting the heel through extension of the metatarsophalangeal joint and plantar flexion.

##### (2) Weight bearing training

Participant stands with his feet at pelvic width when looking at the front, and a short foot exercise was performed that pulled the first metatarsophalangeal joint toward the heel in a standing position. Then, the walker was held and the weight was moved forward so that approximately 30° of dorsiflexion occurs at the

(A) (B)

**Figure 2. Increasing foot awareness**

ankle. Next, the walker was held in front, and the heels were lifted and slowly lowered.

(3) Facilitating weight shifting

The tension on the plantar fascia was increased by raising the heel from a standing position without holding the walker. Then, a standing posture was set up on the support surface with the middle part of the foot removed so that the weight loaded inward could move outward (Figure 3), and short foot exercises are performed. Afterwards, the walker was held, and the weight was shifted forward so that 30° of dorsiflexion occurs while maintaining the short foot posture.

2) Conventional physical therapy

This study program proceeded with wearing a Orthosis or insoles. The treatment consists of improving alignment through joint mobilization and stretching, and strengthening exercises through weight transfer and weight bearing. The treatment is mainly focused on solving the patient's individual problem.

## 3. Measurement

1) Arch Height Index

In this study, the arch height index (AHI) was used to compare the morphology of the foot before and after the intervention. The arch height index can be nor-

**Figure 3. Facilitating weight shifting**

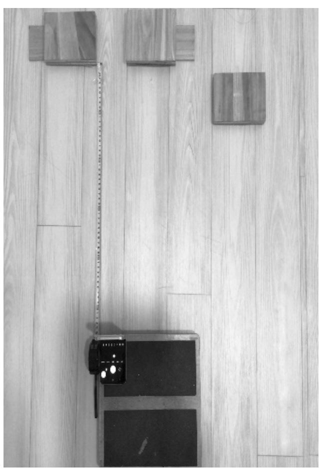

**Figure 4. Taking pictures for measuring arch height index**

**Figure 5. Measuring arch height index through Image J program**

malized to the instep length to track the growth and development of children's feet.[13)]

*The formula for calculating the AHI is = instep height / instep length*

Instep height represents the distance between the highest point on the instep and the support surface at 50% of the foot length, while the instep length is the vertical distance from the back of the heel to the joint line of the first metatarsophalangeal joint, which indicates that the height of the instep at 50% of the foot.[14)] When Drefus et al[13)] obtained arch height index for children, 0.345 or less in a standing position was classified as pes planus, > 0.345 as normal, and 0.37 or more as pes cavus.

In this study, the arch height index was measured using the method suggested by previous studies.[15)] The feet of the subject to be photographed are placed on two blocks with a height of 4.5 cm, centering on the head of the metatarsal bone, with the forefoot and heel so that about 90% of the body weight is loaded, and the other foot is placed on the third block on the side. The camera was then placed on a 4-cm-high block 55 cm away from the middle of the foot to take a picture (Figure 4). The images taken this way were measured by marking the front of the toe and the end of the heel in ImageJ with a 4-mm-size circular marker (Figure 5). ImageJ is a Java-based image processing program developed by the National Institutes of Health for research purposes. It has a high reliability of 95% between measurements and can obtain the length and width of the subject of a photograph taken.[16)]

#### 2) Temporal distance gait analysis

The method used by Boenig[17)] was applied for temporal distance gait analysis using footprints. The child gets ink on his feet and walks on an 8-m-long sheet of paper. The heel strike of the first step across the line marked at the first 1.5-m distance was measured to the toe off of the last 1.5-m distance. The velocity and number of steps were calculated by measuring the walking time of 5 m in the middle, excluding the first and last 1.5 m, and the step length, stride length, step angle, and foot width were measured with three footsteps in the middle. The test-retest reliability of gait analysis using footprints was r=0.95.[17)]

### 4. Data Analysis

This study was analyzed using SPSS/window 18.0 version. The average value and standard deviation for the general characteristics of the research participants were expressed using descriptive statistics. The Shapiro-Wilk test was performed to verify the normality of the dependent variable, and a non-parametric test was used because the measured values did not satisfy the normal distribution. Before and after differences in Arch height index, and gait in the study and control groups were compared using the Wilcoxon signed-rank test, and the differences between groups were analyzed using the Mann-Whitney U test. All statistical significance levels ($\alpha$) were set at .05.

## III. Results

### 1. General characteristics of the subject

In this study, 18 subjects who met the subject selection criteria participated (Table 1).

### 2. Changes in foot morphology

The amount of change before and after the Arch height index was compared using ImageJ. Study group increased from 0.311 before treatment to 0.313 after treatment, but was not statistically significant, and it increased from 0.312 before treatment to 0.315 after treatment in the control group, but was not statistically significant ($p$>.05). A comparative analysis was conducted between groups on the change in the Arch height index, and there was no significant difference was noted ($p$>.05) (Table 2).

**Table 1. General characteristics of the subjects**

| Variables | | Study Group (n=9) | Control Group (n=9) | $x^2$/t | *p* |
|---|---|---|---|---|---|
| Gender (M/F, %) | | 5/4(56/44) | 6/3(67/33) | 0.234 | .629 |
| Age (year) | | 8.56±02.21 | 7.56±01.77 | 0.997 | .334 |
| Height (cm) | | 122.67±14.43 | 112.41±13.49 | 1.468 | .161 |
| Weight (kg) | | 24.50±13.96 | 23.28±07.29 | 0.219 | .829 |
| Podoscope (n) | Grade 1 | 2 | 2 | | |
| | Grade 2 | 5 | 3 | | |
| | Grade 3 | 2 | 4 | | |

**Table 2. Comparison of foot morphology within & between groups**

| Variables | Study Group(n=9) | | | Control Group(n=9) | | | p |
|---|---|---|---|---|---|---|---|
| | Pre | Post | p | Pre | Post | p | |
| AHI | 0.311±0.196 | 0.313±0.196 | .286 | 0.312±0.210 | 0.315±0.018 | .170 | .355 |

Note. AHI: Arch Height Index

### 3. Changes in gait ability

The velocity increased from 67.60 to 84.28 cm/s, the step length increased from 36.24 to 38.77 cm in the study group but was not significant, and the stride length increased from 69.17 to 79.33 cm, which was statistically significant($p$<.05). The number of steps decreased from 17.11 to 14.56 but was not significant. The angle of detection decreased from 8.78° to 7.89°, and the foot width decreased from 14.96 to 14.44 cm but was not significant ($p$>.05). Velocity decreased from 80.77 to 79.04 cm/s, Stride length increased from 35.80 to 37.92 cm, and step length decreased from 73.12 to 72.74 cm in the control group. The number of steps decreased from 15.78 to 15.44 but was not statistically significant; the angle of the step increased from 16.44° to 17.56°, and the foot width increased from 12.16 to 13.16 cm ($p$>.05). The amount of change in walking ability between the study group and the control group showed a significant difference in the number of steps ($p$<.05) (Table 3).

## Ⅳ. Discussion

This study was conducted to investigate the effects of strengthening intrinsic foot muscles on foot morphology and gait abilities in pes planus children with developmental delay. Strengthening intrinsic foot muscles is effective in improving the foot morphology and gait ability of pes planus children with developmental delays compared with conventional physical therapy using orthosis and insoles.

Despite the relative ease of applying toe flexion exercise to the subjects, short foot exercise was ap-

**Table 3. Comparison of gait parameters within & between groups**

| Variables | Study Group(n=9) | | | Control Group(n=9) | | | |
|---|---|---|---|---|---|---|---|
| | Pre | post | p | Pre | post | p | P |
| Gait velocity (cm/s) | 67.60±29.81 | 84.28±37.05 | .066 | 80.77±16.78 | 79.04±24.39 | .953 | .122 |
| Step length (cm) | 36.24±11.87 | 38.77±14.62 | .314 | 35.80±11.77 | 37.92±04.79 | .767 | .895 |
| Stride length (cm) | 69.17±22.24 | 79.33±26.19* | .038* | 73.12±19.00 | 72.74±11.25 | .374 | .171 |
| Step | 17.11±05.33 | 14.56±06.27 | .108 | 15.78±02.90 | 15.44±03.00 | .496 | .011* |
| Angle (°) | 08.78±06.06 | 07.89±08.93 | .306 | 16.44±17.45 | 17.56±17.87 | .483 | .478 |
| Foot width (cm) | 14.96±06.50 | 14.44±05.73 | .859 | 12.16±04.82 | 13.16±04.61 | .407 | .377 |

Note. *: p<.05

plied because the intrinsic muscles of the foot can be contracted in isolation, and the muscle activation of the abductor hallucis is higher than that of toe flexion.[18] In addition, previous studies have suggested that short foot exercise is more effective in decreasing navicular drop than wearing orthosis, which is consistent with the purpose of this study.[12] However, since the subjects in this study were children, it is difficult to expect the perfect effect of the intervention, so it was not possible to have a significant difference before and after the intervention. In this study, the arch height index was measured by the method suggested by Pohl et al[15]. They reported that variables occur depending on the environment or the camera position during filming. In addition, deformities or edema of the foot can cause potential error. The block used in this study has a narrow base of support for children, making it difficult to measure as it increased visual instability and added restrictions to maintaining a static posture. In addition, Gjelsvik[19] stated that clinically meaningful changes are made by treatment, and that treatment effects require a certain level of intensity and a duration of more than 12 week. The study group strengthened the intrinsic muscles of the foot using a footrest with the middle part of the foot removed focusing on short foot exercises. The control group received conventional physical therapy by providing support to the midfoot through an orthosis or insole.

In the intervention of this study, four wooden boards with a width of 9 cm, a length of 14.5 cm, and a height of 9 mm were continuously attached to the footrest from which the middle part of the foot was removed, and a non-slip mat was attached to the bottom. Two pairs of footrests manufactured in this manner were prepared, one pair supporting the forefoot, including the metatarsal head of each foot, and the other pair supporting the heel bone so that the child could stand on the footrests. Four wooden boards with widths of 6 cm, lengths of 20 cm, and heights of 9 mm were stacked and attached for the footrests on the outside of the foot, and the fourth and fifth toes were supported so that they could stand. Ledoux[20] reported that pes planus have a greater weight load on the area under the big toe than neutrally aligned feet, and the midfoot was reported to have the high pressure compared with the pes cavus and neutrally aligned feet, and plantar pressure was the lowest in the back of the foot.[21] Considering this, the footrests with the middle part removed was made wider than 318 mm, which was the maximum of the average hip width and 244 mm, the maximum of the average straight line length, measured in the 2011 population in a body survey of 7 to 13year olds.[22] Inward spreading of the foot was noted, and the weight was transferred to the outer part and back of the foot. Dorsiflexion was allowed to occur at the ankle by leaning forward in the treatment intervention because dorsiflexion can increase the stability of the hindfoot by reducing the laxity of the fibrous membrane and ligament of the back of the foot.[23]

The strengthening of the abductor muscle was thought to improve Single limb support based on the result of the study, and the Step length and stride length increased accordingly. These results suggest that the gait ability of the study group improved according to Bly's assertion that step length increases as gait matures.[24] The amount of change in gait ability between the study and control groups showed a significant difference in the number of steps ($p$<.05). This is because the Single limb support was improved. Thus, the step length increased, and the number of steps decreased accordingly. This resulted in the activation of the abductor hallucis muscle, which is the main training muscle for short-foot exercises, and the abductor hallucis plays a very important role in the first metatarsal joint and stabilizing standing posture using one leg.[25]

A decrease in the number of footprints while walking the same distance indicates a change in velocity, and an increase in gait velocity implies a decrease in energy consumption and thus efficient walking.[26] This is consistent with previous study suggested that short foot exercise has a positive effect on the gait velocity of stroke patients.[27] In addition, An et al[28] reported that foot perception training by facilitating foot intrinsic muscles improves balance and gait abilities.

A limitation of this study was that it was not possible to control the environment other than the intervention time, and foot intrinsic muscle strengthening was performed; however, it was not measured with electromyography; therefore, knowing the exact numerical change in muscle strength increase was not possible. In addition, as this is the result obtained by treating 18 people in a specific region and medical institution, it cannot be generalized to all children with developmental delays and pes planus. In the future, various interventions should be attempted for children with developmental delays who have pes planus in addition to this study.

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