# Electrical Stimulation Versus Voluntary Exercise on the Navicular Height, Calcaneal Pitch Angle, and Cross-Sectional Area in Healthy Subjects: A Single-Blinded Randomized Controlled Trial

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## Abstract

The important function of the intrinsic foot muscles is the dynamic stabilization of the medial longitudinal arch (MLA). Several studies have reported that implementing short foot exercise (SFE) and electrical stimulation (ES) amid the intrinsic foot muscles may increase MLA height. Hence, the aim of this study was to compare the effects of ES versus SFE on navicular drop (ND), calcaneal pitch angle (CPA), and cross-sectional area (CSA) of the abductor hallucis (AbdH) muscle. 20 healthy female subjects were randomly assigned to undergo ES (n=10) or SFE (n=10). SFE performed 30 repetitions whereas 20 min per day for ES, 3 days/week, for 4 weeks. ND, CPA, and the CSA of the AbdH muscle were assessed before and after intervention. The results showed that ES group significantly decreased in ND after training ($p<0.05$) without significant differences between groups. The CPA is a little change in both groups (SFE = $0.4^o$ and ES = $2.4^o$; $p>0.05$). The CSA of the AbdH muscle in both groups was increased (ES =10.93 $mm^2$ and SFE=7.44 $mm^2$; $p<0.05$) with no significant difference between ES and SFE. These results demonstrated that ES and SFE alone could improve intrinsic foot muscle size. Nevertheless, ES tended to increase MLA more than SFE alone. Hence, ES can be considered as an alternative treatment to increase MLA and intrinsic foot muscle size.

***Keywords:*** *electrical stimulation, voluntary exercise, cross-sectional area, navicular height*

## Introduction

The foot is an importantly complex structure which serves as the propulsive organ and supporting pedestal during weight bearing throughout locomotion[1]. Foot function efficiency depends on the integrity of the medial longitudinal arch (MLA)[2]. The MLA is the primary structure responsible for stability and resiliency of the foot load[3]. The most significant arch static contributors are the plantar fascia, the long and short plantar ligaments, and the spring ligament. Whereas, the intrinsic and extrinsic foot muscles play a role in dynamic contributors. However, recent evidence has suggested that the intrinsic foot muscles (IFM) play a crucial role in supporting MLA[4-5].

Previous studies have confirmed the function of the IFM. A study by Fiolkowski et al.[6] and Headlee et al.[7] demonstrated the tibial nerve inhibition amid the IFM in addition to exercise until IFM fatigue increased significantly enough to render a navicular drop (ND). Moreover, previous studies demonstrated that muscle strength had significant correlation with cross-sectional area (CSA)[8]. IFM weakness and atrophy commonly result in several conditions such as plantar fasciitis[9],

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hallux valgus, and pes planus[10]. Pes planus is associated with heel eversion and forefoot abduction. In the long term, these changes may be a cause of overuse injuries[11], and disability[12]. Therefore, the rehabilitation and prevention of these problems are resultant of necessarily reinforcing IFM strength aimed at improving MLA by increasing CPA.

Several studies have reported the beneficial effects of IFM training, especially short foot exercise (SFE) on ND[9] and the CSA of the abductor hallucis muscle (AbdH)[11]. Jung et al. [13] reported that SFE can improve IFM activity and prevent the fall of MLA.

Today, electrical stimulation (ES) is an alternative method for the rehabilitation of a paralyzed muscle as well as strength promotion[14] because this treatment has the ability to isolate contraction of the desired muscle group[15]. A study by Fourchet et al.[16] found that neuromuscular electrical stimulation of the abductor hallucis (AbdH) muscle decreased ND post training. Moreover, ES significantly increased CSA of the vastus lateralis, vastus medialis, and vastus intermedius muscles post training[17].

Conversely, some evidence suggests that combined ES in addition to exercise training is more effective for strengthening the muscles than exercise alone[18-20]. Nevertheless, the short-term effect of ES as an intrinsic foot strengthening exercise method has to date not been discussed. Therefore, the purpose of this study was to compare the effects of ES versus SFE alone on ND, calcaneal pitch angle (CPA), and CSA of the AbdH muscle.

## Materials and Method

### Design and setting

A Single-blinded randomized controlled trial was used in this study. Subjects were recruited from Chonburi province, Thailand. This present study was approved by the Khon Kaen University Ethics Committee in Human Research (TCTR20180511002). All subjects were randomly assigned to undergo combined ES group or SFE. Numbered lots (1, SFE; 2, ES) were placed in sealed opaque envelopes by physiotherapist 1. The subjects were then allocated for intervention by physiotherapist 2.

Participants

Twenty healthy females between 18-40 years of age volunteered to participate. All subjects reported no contraindication of ES, and no lower extremity orthopedic or neurologic disorders history within the previous 6 months.

Outcome measures

The measurements of outcome in this study were assessed at the site of the dominant foot prior to and 4 weeks succeeding training intervention by the same investigators.

*Navicular drop*

The differences in distances between navicular tuberosity and the floor while sitting and standing are defined as the ND. Subjects sat on a chair with the hips, knees, and ankles at a 90°. Each subject was marked for their navicular tuberosity using a permanent marker. The investigator measured navicular tuberosity height utilizing a digital vernier caliper (CD-20AX, Mitutoyo, Kawasaki, Japan). Then, subjects were instructed to stand with their weight equally distributed between legs. The knees were extended and feet relaxed. Navicular tuberosity height was then remeasured. The test was performed three times with the mean value of three measurements calculated. Consequently, ND was calculated by subtracting navicular height standing from the sitting measurement.

*Calcaneal pitch angle*

Participants stood on the platform with equal weight on both legs, with knees extended and feet relaxed, while radiological technicians placed the radiographic film between their feet. Calcaneal pitch angle (CPA) is defined as a line drawn extending from inferior portion of the calcaneocuboid joint to the inferior border of the calcaneus, a second line extending from the inferior aspect of the medial sesamoid bone to the inferior border[21]. All films were read and calculated by a radiologist.

*Cross-sectional area of abductor hallucis*

An ultrasound machine (M5 series, Shenzhen Mindray Bio-Medical, China) with 7.5 MHz linear array probe was applied to render an image of the AbdH muscle. Subjects lie down in the supine position with a 15° knee flexion with the ankle in the neutral position. An ultrasound probe with a sufficient amount of gel was placed perpendicularly to the AbdH muscle. The anterior margin of the ultrasound probe should be positioned 1cm posteriorly to the navicular tuberosity with minimal pressure. CSA mean was calculated from three separate images using software Image J V.1.52b (NIH, Bethesda, MD, USA). The CSA measures the desired area by tracing the muscle border[22].

### Procedure

ES training was performed using an electrical stimulator (Endomed 482, Enraf-Nonius Co., Netherlands) with two electrodes. The passive electrode was placed behind the head of the first metatarsal bone in sitting position. Meanwhile, the active electrode was placed over the AbdH motor point. Each individual was trained at 85 Hz, 5 seconds pulse duration, and 6 seconds pause duration for 20 minutes each session, once daily covering 3 sessions weekly for 4 weeks. Intensity was adjusted to each subject's maximum tolerance without pain.

Subjects in SFE group performed in the sitting position. Subjects were asked to place their feet on the ground. Then, they attempted to pull the head of metatarsal bones toward the heel without flexing the toes, nor lifting the forefoot and heel from the ground. Exercise training was performed for 30 repetitions/day, 3 days/week, for 4 weeks. Each repetition required a contraction of 5 seconds. Throughout the 4 weeks, subjects were not allowed to participate in any other exercise.

## Statistical Analysis

All data were analyzed using SPSS version 19. All data are presented as mean ± standard deviation. The student t-test was implemented to compare demographic characteristics. Changes to ND, CPA, and CSA. in the AbdH muscle between groups at baseline and 4 weeks post-intervention were compared utilizing the independent student t-test. A p-value of less than 0.05 was considered statistically significant.

## Results

#### Demographic Characteristics

Subjects' demographic and clinical characteristics are shown in Table 1 with no differences between groups.

**Table 1 The baseline outcome measures in each group**

| Characteristic | ES (n=10) | SFE (n=10) |
|---|---|---|
| Age (years) | 20.60±0.89 | 20.40±0.55 |
| Height (cm) | 158.40±7.30 | 158.20±6.42 |
| Weight (kg) | 50.40±6.89 | 53.50±4.72 |
| BMI (kg/m$^2$) | 19.80±1.56 | 21.59±1.13 |
| PCA (degree) | 18.70±1.89 | 20.40±2.76 |
| ND (mm) | 6.28±1.50 | 7.47±2.31 |
| CSA (mm$^2$) | 191.25±35.43 | 190.24±25.33 |

ES, Electrical stimulation; SFE, Short foot exercise; BMI, Body mass index; PCA, Calcaneal pitch angle; ND, Navicular drop; CSA, Cross-sectional area

Navicular drop, calcaneal pitch angle, and cross-sectional area

After 4 weeks, there is a little change in CPA in both groups (SFE = 0.4° and ES = 2.4°) with no significant change of the CPA between groups (Figure 1A). The results showed a significant decrease in ND in ES amid the SFE group subsequent to training, whereas the SFE group did not reach significance. However, there were no significant differences between groups (Figure 1B). The CSA of the AbdH muscle in both groups was increased (ES =10.93 $mm^2$ and SFE=7.44 $mm^2$; $p<0.05$) without significant differences between groups (Figure 1C).

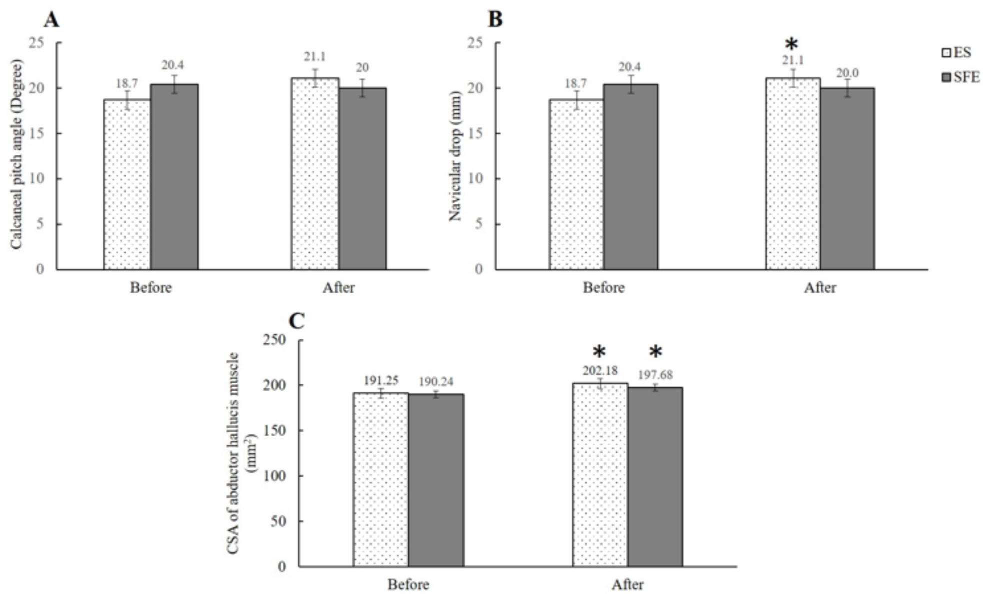


**Figure 1. Effects of ES and SFE on CPA (A), ND (B) and CSA (C). Measurements were made before and after 4 wks intervention. Data are given as mean and SD (N = 20). *Significant difference from baseline testing ($p < 0.05$).**

## Discussion

The purpose of the current study was to compare the effects ES versus SFE on ND, CPA, and CSA amid the AbdH muscle. Hence, our results demonstrated that 4 weeks of ES tend to increase MLA height, CPA, and CSA more than SFE. More recently, a study conducted by Kaur et al.[22] showed the use of ES in flexible flatfoot significantly decreased ND after 3 weeks. This is consistent with a study by Fourchet et al.[17] which revealed that stimulation of the AbdH muscles in young adults significantly caused ND to decrease after 3 weeks of training.

The possible mechanism was the ES involved in the reverse motor unit recruitment in the muscles. Large fibers have a lower threshold for stimulation, thus they are recruited preferentially, resulting in a greater potential for force production[23]. Therefore, ES can facilitate muscle strength to gain more rapidly than exercise alone[24]. Moreover, a possible mechanism that used to describe a changed of the height of navicular in this result was "the closed kinetic chain". Changes in calcaneal position (i.e. CPA) affect the navicular via subtalar joint motion[25].

Moreover, the results in this study incorporated measured muscle size measurement which is considered to be one of the preeminent determinants of muscle strength[10]. A previous study reported that the cases of IFM weakness presented a significant reduction in CSA[10,26]. Recent studies on the uses of SFE or ES to treat flatfoot suggest that both methods tend to improve plantar intrinsic foot strength[27].

In a similar way, the results of this study support a previous finding in that ES and SFE tends to increase muscle size. CSA was significantly increased after 4 weeks of intervention. Whereas, the previous study demonstrated that CSA may increase after 5-12 weeks of strength training[28]. Gondin et al.[17] found the CSA of the quadricep muscles increased after 8 weeks of ES. Jung et al.[11] demonstrated that AbdH muscle CSA significantly increased after 8 weeks of SFE.

The finding in terms of increased the AbdH muscle CSA may be described by the proper strength training intensity and duration. An increase in muscle size using NMES and exercise alone rendered the enlargement of muscle fibers due to the resistance training mechanism[29].

This study has some limitations. Firstly, the sample size was small. Secondly, the young subjects cannot be generalized to fit the general population. Lastly, we selected subjects without muscle weakness. In the future, the study will be conducted among atrophy condition and long term study.

In conclusion, these results demonstrate that ES and SFE alone, can improve intrinsic foot muscle size. An increase in AbdH muscle size is one factor relating to IFM strength. Hence, ES tended to increase MLA and CPA over SFE alone. Consequently, ES may be recommended as an alternative treatment to increase MLA.

**Conflict of Interest**: The authors declare that they have no conflict of interest.

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**Informed consent:** Informed consent was obtained from all individual participants included in the study.

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