

# Comparison of the thickness of the gastrocnemius through ultrasonography during heel-drop exercise performance

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**Objective:** This study was aimed to compare the thickness and pennation angle of gastrocnemius through ultrasonography during the heel-drop exercise on ankle dorsiflexion angle.

**Design:** Cross-sectional study.

**Methods:** Nineteen normal adults in their 20s had voluntarily participated in this study. All subjects performed the ankle heel-drop exercise with ankle dorsiflexed to 0°, 10°, and 20°: heel-drop exercise with ankle dorsiflexed to 0° was executed on floor-level, heel-drop exercise with ankle dorsiflexed to 10° on a wooden-block of 2.3 cm in height, and heel-drop exercise with ankle dorsiflexed to 20° on a wooden-block of 5.5 cm in height. In each regimen, the subjects completed a session of 100 heel-drop exercises (10 repetitions×10 sets; with 30 seconds rest following each set; with 24 hours rest following each exercise). Before and immediately after each heel-drop exercise, the thickness and pennation angle of gastrocnemius were measured using an ultrasonography.

**Results:** After the performance of the heel drop exercises with ankle dorsiflexed to 0°, 10°, and 20°, the thickness of the gastrocnemius was significantly higher than pre-exercise ( $p<0.05$ ), and furthermore heel-drop exercise with ankle dorsiflexed to 10° was significantly higher than exercise with the ankle dorsiflexed to 0° ( $p<0.05$ ). However, as for the pennation angle of the gastrocnemius, there were no significant changes after each heel-drop exercise.

**Conclusions:** This finding suggest that the heel-drop exercise with ankle dorsiflexed to 0°, 10°, and 20° is effective on the strengthening of the gastrocnemius. Furthermore, the heel-drop exercise with the ankle dorsiflexed to 10° is more effective than with the ankle dorsiflexed to 0°.

**Key Words:** Ankle joint, Gastrocnemius muscle, Muscle strength, Ultrasonography

## Introduction

Falling is defined as the process of falling or landing on the floor due to sudden, involuntary changes in posture [1]. Falls are considered as one of the most common injuries that can occur to humans from the day they are born to when they become an elderly adult. Worldwide, it is reported annually that 30% of falls occur amongst those who are over the age of 65 years [2]. It has been stated that lower extremity strength and balance are needed to prevent falls [3], and Wolfson *et al.* [4] has reported that decreased balance was

related to weak ankle muscle strength. Lamontagne *et al.* [5] has found that decreased control of the ankle decreases gait and balance abilities, which causes an increase in fall risk. The body has the ability to regain standing balance by using the ankle strategy, hip strategy, or both strategies [6]. The ankle strategy is used to counteract against a small amount of sway [7], and is usually the first strategy to be used for recovering standing balance [6].

The ability to maintain balance during anterior and posterior sway is dependent upon the muscle activation of the anterior tibialis and gastrocnemius medialis muscle [8].

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Therefore, it is necessary to increase ankle joint muscle strength and range of motion. Choi *et al.* [9] conducted a study on the use of elastic band for resistive exercises and cushion pads for equilibrium exercises. The results showed significant improvement in balance, gait, and muscle endurance. Son [10] conducted a study involving stroke patients performing ankle dorsiflexion strengthening exercises for balance and Lee [11] investigated the effects of using a stationary bike, ankle stretches, and progressive resistive exercises with elastic bands. Thus several studies examining the effects of implementing ankle exercise programs on balance and gait ability has been conducted.

Therefore, although there are many studies on developing rehabilitation programs for Achilles tendinopathy, the purpose of this study was to investigate for an appropriate heel-drop exercises method for reducing Achilles tendon stiffness and improving gastrocnemius strength, as well as its effects on the gastrocnemius muscle tissue in normal, healthy adults.

Alfredson *et al.* [12] was the first to introduce the heel-drop exercise method. High-intensity eccentric exercises for chronic mid-portion Achilles tendinopathy have been proven to be an effective rehabilitation method [13].

Nevertheless, research focusing on heel-drop exercises and ankle strategy for gastrocnemius muscle strengthening are incomplete, and studies examining for gastrocnemius muscle elongation during heel-drop exercise performance starting from 0° ankle dorsiflexion are continuously being conducted. Also, the most effective position for heel-drop exercise performance has not yet been fully established. Although Jeong *et al.* [14] conducted a study involving heel-drop exercise performance depending on gastrocnemius muscle elongation it mainly focuses on the effects of strain and stiffness of the gastrocnemius aponeurosis-tendon.

Diagnostic ultrasound is a device used to evaluate the structural stability and morphological characteristics of the soft tissue in static and dynamic conditions, such as changes in muscle thickness and muscle fiber cross-sectional area, as well as assess the changes in muscle density through visual imaging [15]. In addition, the cross-sectional area and pennation angle increases with decreasing length of the muscle fiber, which are both important factors in predicting the muscle tension [16].

Therefore, the purpose of this study was to investigate the effects of performing heel-drop exercises with various degrees of ankle dorsiflexion on gastrocnemius muscle thick-

ness and pennation angle in normal, healthy subjects in their twenties, as well as to discover which dorsiflexion angle is the most effective.

## Methods

### Subjects

Nineteen participants in their twenties from B University of Chungcheongnam-do Cheonan-si had volunteered to participate in this study. The participants had an average age of 22.4 years, average weight of 62.5 kg, and an average height of 166.3 cm (Table 1). Participants who exhibited normal ankle dorsiflexion, plantarflexion, no history of ankle injury, no lower extremity injuries, and the ability to perform the heel-drop were included in this study. Participants with neurological or orthopedic ailments of the lower extremities, had regularly received over 3 months of strength training, and wore high heels regularly were excluded from the study. The participants had voluntarily agreed to participate in the study after they had been informed of the study objectives and procedures.

### Equipment

#### Ultrasonography

The LOGIQ P6 PRO diagnostic ultrasound device (GE Inc., Waukesha, WI, USA) was used to assess the thickness and pennation angle of the gastrocnemius muscle. All ultrasound scans were performed using B mode, 10 MHz central frequency, 60 Hz sampling frequency, with a linear transducer of 50% gain, and the muscle thickness was measured using the built-in caliper of the ultrasound [17].

### Heel-drop exercise protocol

Each subject performed the heel-drop exercises in various degrees of ankle flexion (0°, 10°, 20°) in random order, and the diagnostic ultrasound imaging device was used to examine the calf muscle thickness immediately after exercise. Although this study was based on the Alfredson *et al.*'s [12] protocol, which included performing a frequency of 180 ec-

**Table 1.** General characteristics of subjects (N=19)

	Male (n=10)	Female (n=9)	Total
Age (y)	21.9 (2.8)	23 (1.1)	22.4 (2.2)
Height (cm)	171.7 (4.1)	160.4 (6.3)	166.3 (7.7)
Weight (kg)	70 (11.2)	54.2 (6.3)	62.5 (12.1)

Values are presented as mean (SD).

centric heel drops per day, the protocol has been modified to a frequency reported “as tolerated” by the subjects due to the possible development of discomfort, which is based on Stevens and Tan [13] has reported findings that there was no significant difference in improvement according to the frequency of 180 verses “as tolerated”.

#### 0° ankle dorsiflexion heel-drop exercise

After a goniometer was used to confirm 0° of ankle dorsiflexion in barefoot conditions, subjects were instructed to maximally raise the soles of their feet by standing on their tip-toes, and then to return back into 0° of ankle dorsiflexion, which was considered as one heel-drop (Figure 1A).

#### 10° ankle dorsiflexion heel-drop exercise

To set the ankle in 10° of dorsiflexion, 1/3 of the subject’s phalanges and metatarsal bones were placed onto a wooden block that was 2.3 cm in height. After a goniometer was used to confirm 10° of dorsiflexion, subjects were instructed to maximally raise the soles of their feet by standing on their tip-toes, and then to return back into 10° of ankle dorsiflexion, which was considered as one heel-drop (Figure 1B).

#### 20° ankle dorsiflexion heel-drop exercise

To set the ankle in 20° of dorsiflexion, 1/3 of the subject’s phalanges and metatarsal bones were placed onto a wooden block that was 5.5 cm in height. After a goniometer was used

to confirm 20° of dorsiflexion, subjects were instructed to maximally raise the soles of their feet by standing on their tip-toes, and then to return back into 20° of ankle dorsiflexion, which was considered as one heel-drop (Figure 1C).

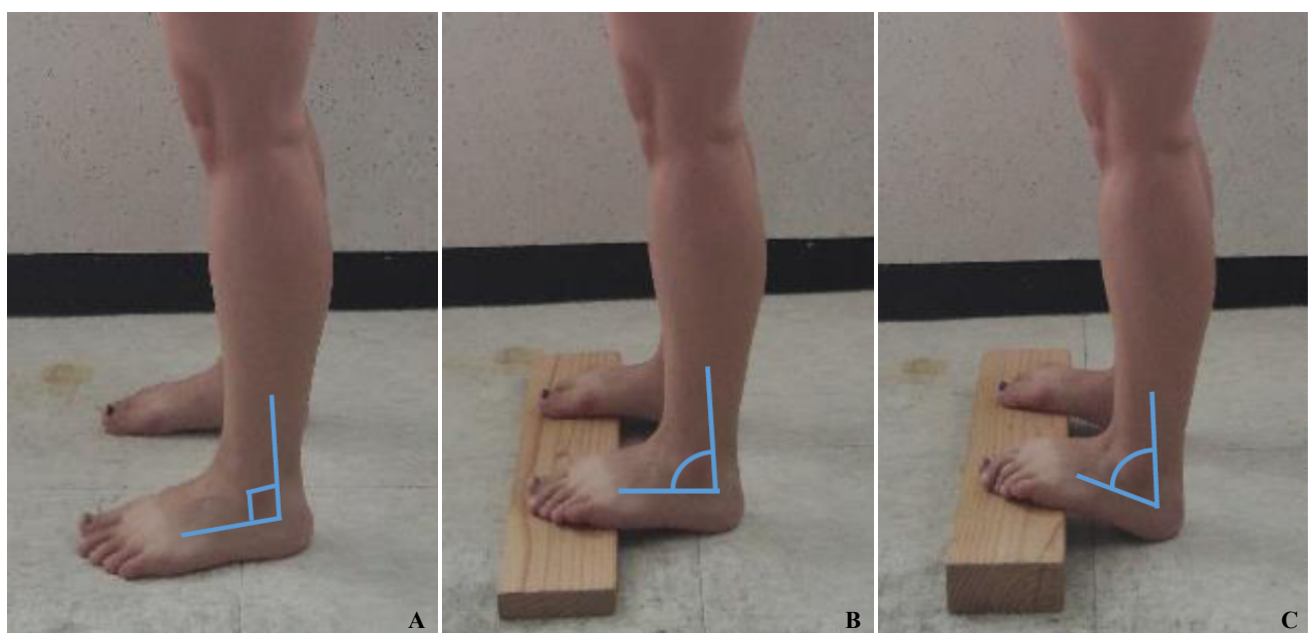
An assistant was available at all times to assist the subjects in maintaining their balance while performing the heel drop exercises at a self-regulated speed. Ten repetitions of each heel drop exercise were considered to be 1 set. A total of 10 sets were performed with a rest period of 30 seconds between each set. Between each of the three dorsiflexion settings for the heel-drop exercises, a 24-hour rest period was provided.

#### Measurements

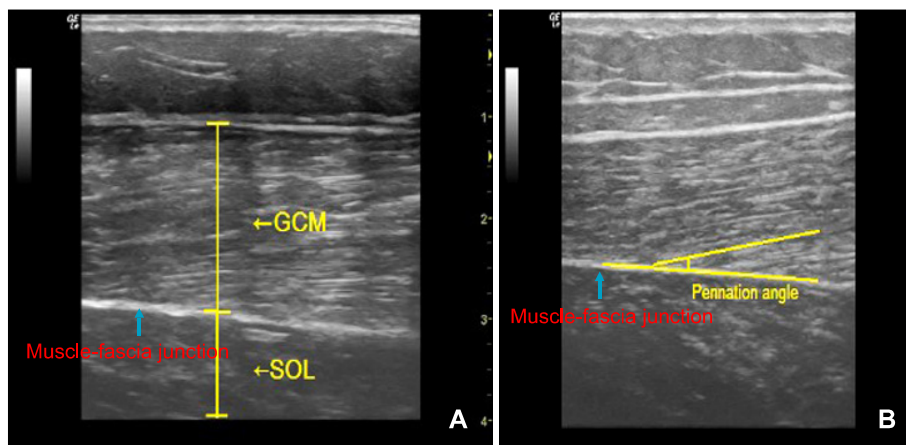
##### *Gastrocnemius muscle thickness and pennation angle*

Subjects were asked to lie prone with ankles off the table during the ultrasound measurement of the gastrocnemius muscle thickness and pennation angle.

Prior to the intervention, the same examiner used a marker pen to enable the exact measurement of the same point on the gastrocnemius muscle immediately after intervention. To optimize the transducer and skin contact, a water-soluble transmission gel was applied prior to the ultrasound scanning process. After the transducer was placed onto the dominant lower extremity behind the knee, between the condyles, 13 cm inferior from the medial popliteal fossa, ultrasound measurements of muscle thickness and pennation angle was



**Figure 1.** Heel-drop exercise with various degrees of ankle dorsiflexion. (A) 0° dorsiflexion, (B) 10° dorsiflexion, (C) 20° dorsiflexion.



**Figure 2.** Ultrasonography imaging on the gastrocnemius muscle (GCM). (A) GCM thickness, (B) GCM pennation angle. SOL: soleus.

**Table 2.** Gastrocnemius muscle thickness post heel-drop exercise (N=19)

	Pre-exercise	0° dorsiflexion	10° dorsiflexion	20° dorsiflexion	F	<i>p</i>
Thickness (cm)	1.74 (0.10)	1.96 (0.07) <sup>a</sup>	2.06 (0.08) <sup>a,b</sup>	2.18 (0.09) <sup>a</sup>	14.24	0.000

Values are presented as mean (SD).

<sup>a</sup>Significant differences compared with pre-exercise ( $p < 0.05$ ). <sup>b</sup>Significant difference compared with 0° dorsiflexion ( $p < 0.05$ ).

**Table 3.** The pennation angle of gastrocnemius post heel-drop exercise (N=19)

	Pre-exercise	0° dorsiflexion	10° dorsiflexion	20° dorsiflexion	F	<i>p</i>
Pennation (°)	8.84 (4.07)	9.42 (4.88)	6.84 (2.93)	8.42 (3.53)	2.14	0.106

Values are presented as mean (SD).

taken place in the sagittal plane of the gastrocnemius medialis.

Medial gastrocnemius muscle, which is in the outer side of the muscle-fascia, was used to measure the gastrocnemius muscle thickness (Figure 2A), and the pennation angle is the angle created between the muscle-fascia junction and the gastrocnemius fascicle. This angle becomes greater during muscle contraction compared to during a resting period (Figure 2B) [18].

#### Statistical analysis

A repeated measures ANOVA was used to analyze the gastrocnemius muscle thickness and pennation angle values according to the various degrees of ankle dorsiflexion during the heel-drop exercises. The Bonferroni post-hoc correction analysis was used to further compare the gastrocnemius muscle thickness according to the various degrees of ankle dorsiflexion. All statistical analysis was performed using the PASW Statistics ver. 18.0 (IBM Co., Armonk, NY, USA)

with a significance level set at  $\alpha = 0.05$ .

## Results

### The thickness of gastrocnemius muscle on heel-drop

There was a significant difference in gastrocnemius muscle thickness depending on the various degrees of ankle dorsiflexion ( $p < 0.05$ ; Table 2). The Bonferroni analysis showed that compared to the pre-exercise period, there was a significant increase in gastrocnemius muscle thickness after performing heel-drop exercises with 0°, 10°, and 20° of ankle dorsiflexion, with an increase in 22 mm, 32 mm, and 44 mm respectively ( $p < 0.05$ ). There was a significant increase of 1 mm in gastrocnemius muscle thickness with 10° versus 0° of ankle dorsiflexion ( $p < 0.05$ ). However, there was no significant difference in muscle thickness when comparing 10° and 20° of ankle dorsiflexion (Table 2).

### The pennation angle of gastrocnemius post heel-drop exercise

There was no significant difference in pennation angle during heel-drop exercise performance with various degrees of ankle dorsiflexion (Table 3).

## Discussion

Research on rehabilitation methods for those who are at risk for falls as well as development of fall risk prevention interventions for the elderly population are being emphasized.

The gastrocnemius contributes to the calf muscle structure of the lower extremity. Through sustained contraction, the gastrocnemius plays an important role in maintaining the center of mass during gait, and is involved in maintaining stability during the performance of lower extremity exercises [19]. In considering a rehabilitation program for gastrocnemius muscle strengthening, it is important to promote gastrocnemius muscle hypertrophy, function, and strength [20].

The heel-drop exercise used in this study is considered as a stretch-shorten cycle exercise that promoted eccentric strengthening of the gastrocnemius, but it also produced an increase in Achilles tendon elongation and a decrease in tendon stiffness, thus leading to changes in the normal length-tension relationship, and it also served as an indicator for the mechanical fatigue [17]. The aim of this study was to investigate for the effects of heel-drop exercise performance according to various lengths of the gastrocnemius muscle and to compare the strength training effects through ultrasound imaging.

Reid *et al.* [21] conducted a study where subjects with and without Achilles tendonopathy performed eccentric calf muscle exercises and through the use of electromyography, results had shown that those without Achilles tendonopathy displayed a greater increase in muscle activation compared with those with Achilles tendonopathy. A study by Lee *et al.* [22] compared the gastrocnemius muscle thickness through ultrasonography during calf-raise exercises performed on various support surfaces and had found a significant increase in gastrocnemius muscle thickness when performed on all support surfaces. These findings can be related to the results of this study, where all of the normal, healthy subjects had shown improvement in gastrocnemius muscle strength after the performance of heel-drop exercises compared with

pre-exercise conditions. A study by Jeong *et al.* [14] examined the effects of heel-drop exercise performance according to various ankle joint range of motion. The study results showed a significant increase in Achilles tendon stiffness when performing the heel-drop exercise while standing on a block compared to performing the exercise on the floor. Tendon stiffness is influenced by the muscle-tendon complex behavior, which reduces the electromechanical delay and cause an increase in rate of torque development [23]. Considering that fact that torque improvement has the ability to decelerate the body movement and plays a role in fall prevention [24], the results of this study demonstrate similar findings in that that there was a significant increase in gastrocnemius muscle thickness when performing the heel-drop exercise with 10° ankle dorsiflexion compared with 0°. Heel-drop exercises are considered to be a dynamic eccentric contraction exercise and an eccentric contraction exercise exerts a greater force than isometric contraction exercise. A greater force exertion generates more strain onto the Achilles tendon cells, and if elongation of the tendon occurs, there is an increase in the ability to store energy, which thereby reduces the muscle fiber bundle contraction speed and enhances the power-speed relationship [25].

In this particular study, there were no significant changes in pennation angle during heel-drop exercise performance with use of various degrees of dorsiflexion. Sanz-López *et al.* [18]. A study by Sanz-López *et al.* [18] found that after subjects had participated in eccentric overload training and running performance, there was an increase in both cross-sectional area and pennation angle of the gastrocnemius muscle had increased after both interventions. Although generally the pennation angle is associated with muscle hypertrophy and that a greater increase in contraction time develops compared to relaxation time, this could not be proven from the results of this study. The lack of reliability in pennation angle measurement methods and transducer position could be considered as a limitation to this study. Although the subjects participated in the heel-drop exercises in two day intervals in order to prevent to carry over effect, however, its effect could not be ruled out. Another limitation was that although participation in intense sports could have been regulated, the daily activities performed by the subjects could not be controlled. In addition, analysis of heel-drop exercises on gastrocnemius muscle thickness and pennation angle was difficult to prove. Therefore, future studies with exercise designs for heel-drop exercises applied simultaneously for fall prevention in the

elderly population, Achilles tendon strain reduction, and ankle joint muscle strengthening are needed.

## Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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