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# The Change of Pennation Angle of Medial Gastrocnemius on Different Heights of Heels

**So-Min Joo, Hee-Joo Kim, Dong-Yeop Lee , Ji-Heon Hong, Jae-Ho Yu and Jin-Seop Kim***

Department of Physical therapy, Sunmoon University, Chung-Nam, Korea; wnthals123@naver.com, heju0927@naver.com, leedy@sunmoon.ac.k, hgh1020@sunmoon.ac.kr, naresa@sunmoon.ac.kr, skylove3373@sunmoon.ac.kr,

## Abstract

**Objectives** This study aims to investigate the effect of pennation angle and surface Electromyography (sEMG) activity of medial gastrocnemius on different heights of high heels by using ultrasonography and sEMG. **Methods/Statistical Analysis**: Twenty eight healthy young females participate in this study. In order to measure the pennation angle and sEMG activity of medial gastrocnemius, we instructed subjects to stand barefoot and wearing two high heels (5 cm and 10 cm). We measured ultrasonography and sEMG activities for three times on three conditions (barefoot, 5 cm, 10 cm) repeatedly and used the mean of measurement values. One-way repeated ANOVA was used to see the difference of individual intervention and Bonferroni's correction for post-hoc was used to that. **Findings**: Pennation angle and sEMG activities in medial gastrocnemius showed significant differences on three conditions (barefoot, 5 cm, 10 cm). **Improvements/Applications**: Furthermore, measurement of muscle activity using ultrasonography is considered useful way because pennation angle and sEMG activity in medial gastrocnemius increased in accordance with the increasing height of heels identically.

**Keywords:** Electromyography Activity. Heel Height, Pennation Angle, Ultrasonography Image

## 1. Introduction

A large number of young women, who prefer looking taller and stylish fashion, like to wear high heels and they wear them in daily lives[1]. Over 65% of college students in their twenty prefer to wear high heels and most of them (19%) prefer to wear 6 to 8 cm of high heels and high rate of women (13.5%) want to wear over 9 cm high heels[2]. It looks like majority of women downplays potential side effects of high heels but high heels actually are known as causing an abnormal deformation of feet and musculoskeletal disorder, including a muscular imbalance between the lower limbs[3]. Frequent wearing high heels overloads feet and as the center of body weight change, form of the body changes and it also has a bad influence on the lower limbs and walking and kinematic and kinetic property changes occur[4,5]. When women are wearing high heels, the center of weight of the upper body is placed frontward and of lower limbs is placed backward[5]. Also, wearing high heels leads to partial modification in center line of gravity of body as a position of spinal column and lower limbs joint are changed by the heels[6]. In the aspect of static and movement, these changes in the lower limb joints, especially in ankle joints have a bad influence[4]. Lee and other colleagues (2009) compared and analyzed, according to the duration of wearing high heels, static balance performance and muscle activity of waist and legs by using surface Electromyography[7]. In[8] analyzed muscle fatigue and feet stability during walking with high heels by using surface Electromyography[8]. However, surface Electromyography, with the characteristic of measurement, has the disadvantage of including sundry signals from soft tissues around the muscle, attached with electrode[9] and can be interrupted by other muscles[10]. Ultrasonography is an equipment to make up for these disadvantages. Because ultrasonography is non-surgical, relatively inexpensive and simple to use, it is often used for in vivo measurement and since it has a high quality temporal resolution, it is useful to have an image of muscle contraction[11,12]. Furthermore, it is an easily por-

**Author for correspondence*

table imaging technique and provides qualitative and quantitative information about characteristic of muscle related with muscle measurement[13]. Nevertheless, most of the former studies were conducted to measure muscle activity by using an Electromyography device. Also, there is no satisfying study of muscle structure of anterior muscle when wearing high heels. Therefore, this study is conducted to identify structural change of gastrocnemius when wearing high heels of each different heights by using ultrasonography to make up for problems in the former studies, measuring muscle activity based on each heights of high heels by using the existing Electromyography and if measuring muscle structure through ultrasonic's is the way to make up for the disadvantage Electromyography has.

## 2. Materials and Methods

For this study, female students of S university participated in the study. The subjects were well explained about the purpose and procedure of this study and all of the subjects were voluntarily participating in this study. 28 female subjects in their twenty participated in the study and they were who are not wearing high heels at least once a week. The subjects who have neurologic or orthopedic problems in their ankles, experience of ankle injury six months ago, uncomfortable feeling in their overall bodies or pain and psychological problems or are pregnant were excluded from the study. 25 subjects, participating in the test, were right leg dominants and 3 subjects are left leg dominants. This study was approved by IRB (Institutional Review Board). General characteristics of the subjects are shown in Table 1. Before the test, the height and weight of the subjects were measured by automatic BMI measuring stadiometer, BSM 370, Korea. To confirm dominant leg of the subjects before the test, the participants were asked to kick a rubber ball. 25 subjects were right leg dominants and 3 subjects were left leg dominants. The subjects wore short pants to attach probes and electrodes on their dominant legs and took off both of their shoes and socks. Inner parts of subject's gastrocnemius were shaved and cleaned with ethyl alcohol. Measurement was done for each of bare feet, wearing 5 cm heels and wearing 10 cm heels (Figure 1). High heels were appropriately chosen by each subject's feet sizes and order for wearing was randomly assigned. For measurement, subjects were asked to stand with their legs apart as their shoulder widths and completely stretch knee joints and maintain the static posture during measurement. Ultrasonic imaging and muscle activity were repeatedly measured three times each for bare feet, wearing 5 cm heels and 10 cm heels and mean of measuring value was used. After each measurement, five minutes break time was given. Ultrasonography, eZono 3000, Germany, 2011 was used to measure a pennation angle of the inner part of gastronicnemius and frequency was 7-10 MHz and it is measured with B-Mode (Figure 2). After leaving a mark on the target body part of the subject to accurately aim at the target body part, measurement was conducted. Enough amount of gel was applied to the gap between skin and probes to minimize skin pressure when taking images. Probes measured as it stayed at a right angle to skin and lower arms were held to prevent shaking to maximize accuracy. For measuring posture, subjects were asked to stand as static and maintain completely stretched form of knee joint. The center of muscle belly of inner part of gastrocnemius was measured[14] (Figure 3). Every image was taken by a same ultrasonographer and the image was taken when the pennation angle of fibers was clarified. Pennation angle of inner part of gastrocnemius was measured by the angle between deep fascia and muscular fiber[15] (Figure 4). The blade angle of inner part of gastrocnemius was measured three times repeatedly by that subjects stood as a static posture in each conditions of bare feet, wearing 5 cm and 10 cm heels. The mean of the three times repeatedly measured value was used for the result value of pennation angle of inner part of gastrocnemius. The subjects wore short pants to put electrodes on their gastrocnemius of the dominant leg and took off both of their shoes and socks. The part, electrodes attached to was shaved and cleaned with ethyl alcohol. Muscle contraction of gastrocnemius was encouraged to attach electrodes so that muscle belly can be seen. After attaching electrode to the center of inner part of gastrocnemius[16], maximum voluntary isometric contraction was repeatedly measured three times and the value for three seconds was used, excluding the first and last one second at the measuring value (Figure 4). After measuring maximum isometric value of inner part of gastrocnemius, muscle activity of inner part of gastrocnemius was measured in a static standing posture as bare feet, wearing 5 cm and 10 cm high heels for five seconds. The mean of three times repeatedly measured values was used for the result value of muscle activity of inner part of gatrocneminus. The measured value of bare feet, wearing 5 cm high heels and 10 cm high heels to the value of Maximum Voluntary Isometric Contraction (MVIC) was quantified as percentage (%MVIC). After each measurement was done, five minutes break time was given. Zero Wire EMG, AURION, Italy, 2009 was used to collect and process Electromyography signals of inner part of gastrocnemius of dominant leg in a static standing posture (Figure 5). Sampling rate of Electromyography signal was 1000 Hz and band pass filter was set as 20-500 Hz. The 28 subjects for this study were calculated by G*Power 3.1 program. All of measuring values were statistically processed by using window SPSS 22.0. Because normality was satisfied by using Shapiro-Wilk, One way repeated

**Table 1.** Subject characteristics (n = 28)

| Characteristic | Subjects |
|---|---|
| Age | 19.64±1.03 |
| Height(cm) | 159.43±3.68 |
| Weight(kg) | 53.50±6.17 |


**Figure 1.** A. Heel of 5 cm and B. Heel of 10 cm.

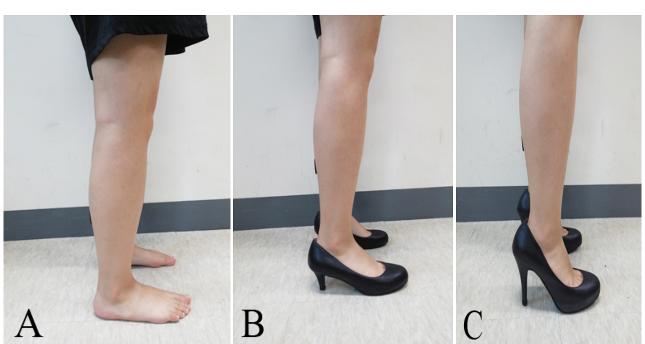


**Figure 2.** A. Bare feet, B. 5 cm and C. 10 cm

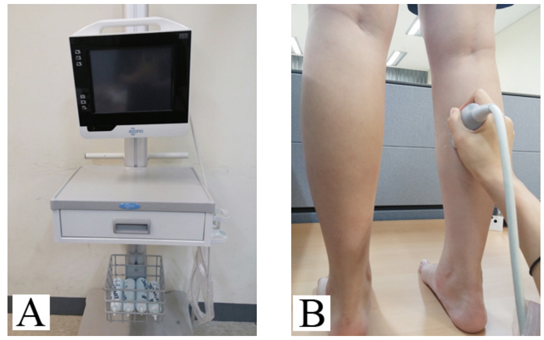


**Figure 3.** A. Ultrasonography and B. Position of probe.

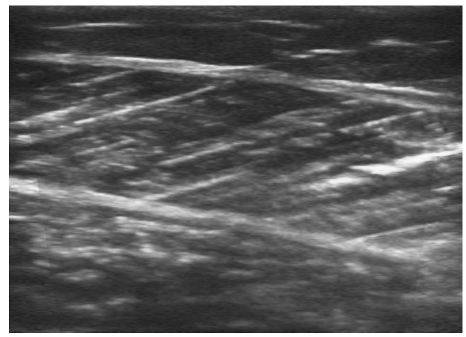

**Figure 4.** Image of the pennation angle of medial gastrocnemius .

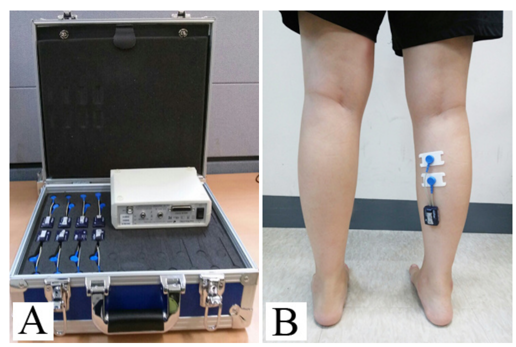


**Figure 5.** A. surface Electromyohraphy and B. The attached location of sEMG electrodes.

ANOVA was conducted to identify the difference between individual interventions. According to the height of the heels, pennation angle and muscle activity were measured three times in each of measuring methods. Post hoc test was conducted in a way of Bonfferoni. p was below 0.05.

## 3. Result

28 subjects were asked to wear 0 cm, 5 cm and 10 cm high heels in a static standing posture. Blade angle of inner

part of gastrocnemius, according to the height of the heels, showed meaningful differences (p<.05). The pennation angle of inner part of gastrocnemius was smallest with 0 cm heels and it increased as the height of the heels increased to 10 cm in Table 2. The result from post hoc test showed that there are meaningful differences between 0 cm and 5 cm heels, 0 cm and 10 cm heels and 5 cm and 10 cm heels (p<.05) (Figure 6). 28 subjects were asked to wear 0 cm, 5 cm and 10 cm heels in a static standing posture. Muscle activity of the inner part of gastrocnemius, depending on each different height of heels, showed a meaningful difference (p<.05). Muscle activity of the inner part of gastrocnemius was smallest when wearing 0 cm heels and it increased as the height of the heels

**Table 2.** Pennation angle of the medial gastrocnemius on different heights n = 28

| Heel height | Medial gastrocnemius(%) |
|---|---|
| 0cm | 55.82 ± 8.54 |
| 5cm | 64.56 ± 11.19 |
| 10cm | 86.45 ± 10.00 |
| *F* | 113.48* |

[a]average ± standard deviation, *p<.05*

**Table 3.** Muscle activity of the medial gastrocnemius on different heights n = 28

| Heel height | Medial gastrocnemius (%MVIC) |
|---|---|
| 0 cm | 6.14 ± 2.78 |
| 5 cm | 17.28 ± 11.77 |
| 10 cm | 40.10 ± 15.73 |
| F | 82.22* |

[a]average ± standard deviation, *p<.05

increased to 10 cm in Table 3. The result from post hoc test showed that there are meaningful differences between 0 cm and 5 cm heels, 0 cm and 10 cm heels and 5 cm and 10 cm heels (p<.05) (Figure 6).

## 4. Discussion

This study is to measure pennation angle of inner part of gastrocnemius and muscle activity, according to each of different height of heels (0 cm, 5 cm, 10 cm), by using a ultrasonography and surface Electromyography and compare the results. The result showed that as the heels increase, the pennation angle of inner part of gastrocnemius increases and muscle activity of inner part of gastrocnemius, measured by using a surface Electromyography device, increases as well. Ultrasonography, providing qualitative and quantitative information about muscle properties, was used for this study, for there have been lots of studies dealing with change of muscle activity of lower limbs based on different heights of high heels so difference was made by using a ultrasonography. Several former studies used surface Electromyography. The study from Choi and other colleagues (2011) compared the influence on muscle around ankle and balance when stimulating front ankle by using a surface Electromyography and the result showed that there is a meaningful difference between all of heels condition[17]. Also[18] after each subjects wore 3 cm, 7 cm and 9 cm heels and maintained the static symmetric and asymmetric standing posture for five minutes, muscle fatigue and muscle activity of tibialis anterior and gastrocnemius were measured and the result showed that there are meaningful differences according to posture and height of heels[18]. As it is described above, even though

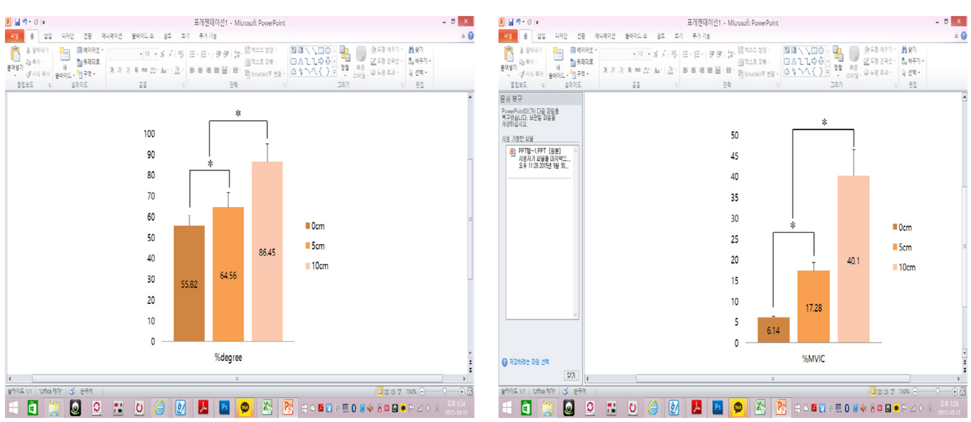


**Figure 6.** Left: Pennation angle changes of the medial gastrocnemius using the ultrasonography and Right: Muscle activity changes of the medial gastrocnemius using the sEMG.

there are lots of studies for proving change of muscle Electromyography according to height of heels, there was no attempt to study by using a ultrasonography to prove the change of pennation angle according to height of heels, therefore, this study was conducted. In[19] reported that gastrocnemius is one of most important plantar digitorum which is responsible for lower limbs movement when gastrocnemius is engaged in walking and provides stability and passive new electronic power in a terminal swing phase and driving force on a vertical line by connecting the movement of feet and knees while walking so it is used when measuring inner structure of muscle in many studies[19]. Furthermore [14]reported that because gastrocnemius is responsible for most of movement, it is a common object for the intervention for improvement of physical function[14]. This supports why this study measured inner part of gastrocnemius among other muscle, participating in feet and ankle movement. In the result of this study, muscle activity of inner part of gastrocnemius, measured by using surface Electromyography, was highest when wearing 10 cm high heels and lowest for bare feet. According to the result of post hoc test, there are meaningful differences between bare feet and 5 cm heels, 5 cm and 10 cm heels and bare feet and 10 cm. This study result agrees with the result of Choi (2011)'s study, proving that wearing high heels, during encouraging ankle strategy, makes overall muscle activity of tibialis anterior, inner part of gastrocnemius, quadriceps femoris increase[16] and the result of study by Oh (2010), saying that when maintaining the standing posture with eye opening and eye closing for a minute with wearing 0 cm, 3 cm and 7 cm heels, the muscle activity of tibialis anterior and gastrocnemius increases as the height of heels increase[9]. The study result showed that the pennation angle of inner part of gastrocnemius, measured by using an ultrasonography, increase equally with the measured value of muscle activity. Pennation angle of inner part of gastrocnemius was biggest when wearing 10 cm heals and smallest with bare feet. And according to the result of post hoc test, there are meaningful differences between bare feet and 5 cm heels, 5 cm and 10 cm heels and bare feet and 10 cm heels. Pennation angle indicates direction angle between muscle fiber and tendon[20]. Commonly human's muscle has a characteristic of pennate and this is related with insertion and origin point of muscular aponeurotic and tendon. When muscle contracts, normal muscle become thicker and muscle fiber become shorter and the pennation angle become larger[21]. In[16] said that the length of muscle fiber in gastrocnemius become shorter during isometric contraction and the pennation angle become larger and the force made by muscle contraction generates tendon's elongation and this phenomenon change the muscular structure[16]. Moreover, the previous study that muscle fiber of gastrocnemius become shorter and simultaneously blade angle increases during plantar flexion[22–24]. These study results can support the result of this study, saying that pennation angle of inner part of gastrocnemius increase as the height of heels increase. As a result, the fact that as the height of heels increase, muscle activity and pennation angle of inner part of gastrocnemius increase simultaneously is proved and it is considered to be that inner part of gastrocnemius is continuously contracted with wearing high heels and wearing high heels for long hours can cause muscle fatigue. The result of this study shows that muscle activity of inner part of gastrocnemius increases as height of the heels increases and it has a same result value with former studies. Pennation angle of inner part of gastrocnemius increased as the height of heels increased as well. Therefore, it is relatively easy to use for measuring muscle activity and ultrasonography[11,12] which is easy to use for muscle contraction image, is considered to be useful to make up for the disadvantage surface Electromyography has.

## 5. Conclusion

As the height of heels increases, both of two variables of blade angle of inner part of gastrocnemius and muscle activity increases and during intra subject reliability analysis, ultrasonography has a higher reliability than surface Electromyography. Therefore, ultrasonography to measure muscle activity is considered to be a useful measurement method.

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