Effects of Raised Heel Insole on Muscle Activity during ankle Sudden Inversion in Normal Adults

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Abstract: - Raised heel insoles increase the plantar flexion angle of the ankle and cause ankle inversion sprain. The purpose of this study was to artificially create an ankle sudden inversion situation, which is a mechanical situation of actual ankle joint damage, and investigate the effect of the raised heel insole on ankle joint muscle activity. The subjects of this study were forty subjects with normal adults. The subjects performed sudden ankle inversion on the trapdoor with no raised heel insole, insole heights of 3cm, and insole heights of 7cm. The application of the raised heel insole was conducted randomly. The subjects performed the trapdoor test three times using dominant feet with a 60-second rest period between tests. This study assessed muscle activity during sudden ankle inversion three times. Raised heel insoles showed a significant decrease in Tibialis Anterior, Peroneus Longus, and Peroneus Brevis muscle activity than no raised heel insole ($p<.05$). Raised heel insoles showed a significant increase in Gastrocnemius muscle activity than no raised heel insole ($p<.05$). Raised heel insoles increase the risk of ankle sprain injury by reducing tibialis anterior and peroneus muscle activity during sudden ankle inversion.

Key-Words: - Raised Heel Insole, Ankle Joint, Ankle Sprain, Ankle Sudden Inversion, Muscle Activity, Normal Adults.

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1 Introduction

Gait is a basic movement necessary for locomotion during active daily living, and is defined as locomotion by moving the body from one point to another by alternately moving the lower extremity and trunk, [1]. The normal gait cycle consists of a stance phase and a swing phase and is a movement that locomotion the body forward while maintaining stability and balance, [2]. However, when gait, the body receives an impact 2-3 times the weight, and it has been reported that a lot of impact is applied to the rare foot, especially during the stance phase, [3]. Therefore, shoes contribute to injury prevention by alleviating the impact on the body. Also, shoes are a basic tool to protect the body and have the function of supporting the body and absorbing shock when gait. In other words, in the case of shoes, the functional aspect is important, [4]. However, recently, apart from functional factors, there is a tendency to prefer high heels as the cosmetic aspect is emphasized to simply compensate for small height or make the legs look longer, [5].

In heel shoes, the normal gait of the lower extremity is difficult, and as the positions of the vertebral column and low extremity joint change, the center of gravity of the body changes, and the longitudinal arch becomes higher, [6]. Additionally, stability is reduced due to a high heel, causing compensation in the knee joint and hip joint. Additionally, high-heeled shoes increase plantar flexion of the ankle joint during gait and affect supination and pronation motion of the foot during gait, [7]. These changes cause musculoskeletal problems such as muscle weakness, ligament damage, joint adhesion, and improper body alignment at the ankle joint, [8]. Balance refers to a process caused by coordinated activities in the proprioceptor and mechanical aspects. Continuous wearing of high heel shoes causes abnormalities in the Somatosensory system and proprioceptor around the ankle joint and changes the normal mechanism of the foot, affecting balance function, [9]. It was said to bring about change. This can lead to various adverse effects on balance, gait, and ankle. According to previous studies, it has been reported that wearing Raised heel insoles has a negative effect on balance and gait, [10].

In particular, ankle sprains can be caused by high heels, and ankle sprains are the main cause of activity disorder, and symptoms such as pain, edema, muscle weakness, and instability appear, [11]. Damage to the Anterior Talofibular Ligament (ATL) and Calcaneofibular Ligament (CFL) is common in most ankle sprains. Due to this damage, the stability between the talus and fibula and between the calcaneus and fibula decreases, leading to chronic ankle instability, [12].

According to many previous studies, using high heels has a negative effect on balance and gait function and the body as a whole. However, there is a lack of research on the effects of high heels on the ankle joint in the context of actual mechanical processes and injury mechanisms. In addition, despite the increasing use of raised heel insoles by modern people, there is a lack of research on the risks and negative effects of raised heel insoles. Therefore, the purpose of this study was to artificially create an ankle sudden inversion situation, which is a mechanical situation of actual ankle joint damage, and investigate the effect of raised heel insoles on ankle joint muscle activity. And, this study aims to investigate the relationship between raised heel insoles and ankle injuries.

2 Methods

2.1 Subjects

The subjects were 60 normal adults attending Y University College from September to October 2023. The criteria for determining a normal ankle joint were that there was no clear history of ankle joint damage through a questionnaire, no ankle symptoms such as pain or swelling, and no instability due to the talar tilt test or anterior drawer test through a physical examination. The data analysis of this study was approved by the Institutional Review Board of Daegu University.

2.2 Study Protocol

To evaluate the effect of raised heel insole on normal adults, bare feet and insole heights of 3cm and 7cm were applied to the subjects. The order of application of the insole was determined randomly. The subject was asked to stand on a trap door wearing bare feet or shoes with insoles, and an ankle sudden inversion situation was applied. Additionally, because vision can affect the experimental results, measurements were made with eyes closed. Muscle activity was measured before and after measurement. The reference value of muscle activity was expressed as a ratio of the average value of activity measured for 2 seconds from the onset of muscle activity when inversion of the ankle joint was induced. The measurements were made 3 times on bare feet, with insole heights of 3cm and 7cm, and the average value was used. Since muscle fatigue may increase during measurement, sufficient rest of 5 minutes was provided between measurements (Figure 1).

Fig. 1: Raised Heel Insole

2.3 Measurement Tools and Measurement Methods

2.3.1 Trap Door

For examination, a trap door was employed to analyze the ankle injuries kinematically, [13]. The subject is asked to stand on a trap door with the leg to be tested on the active board and the leg not being tested on the stationary board, with both feet parallel, and then place both arms naturally and look straight ahead. To prevent the subject from predicting, a trap door is activated to induce an inversion motion of the ankle joint. The trapdoor platform rotated in an inverted manner by 25° from the neutral standing position. The subjects performed the trapdoor test three times using dominant feet with a 60-second rest period between tests (Figure 2).

Fig. 2: Trap door

2.3.2 Electromyography

Electromyography measurements were performed at the tibialis anterior, peroneus longus, peroneus brevis, and gastrocnemius of the dominant leg using surface electromyography (MP35, Biopac, Goleta, CA, USA) in the setting of sudden ankle inversion. To measure electromyography, surface electrodes were attached after hair removal and ethyl alcohol disinfection of the electrode attachment area. The electrodes were placed as described by the surface EMG for non-invasive assessment of muscles (SENIAM) protocol, [14]. To measure the tibialis anterior, it was attached at the upper 1/3 of the line between the tip of the fibula and medial malleolus, to measure the peroneus longus, it was attached at a point 3cm distal to the fibular head, and to measure the peroneus brevis, it was attached at a point 5cm proximal to the lateral malleolus. It was attached to the tendon behind the fibula, and to measure the gastrocnemius, it was attached to the upper third of the line between the fibular head and the calcaneus. To eliminate noise caused by the movement of the wire and ensure that the electrode adheres well to the skin, tape and elastic bands were used to fix the wire and electrode. Electromyography signals were collected at a signal acquisition rate of 1000Hz sampling rate and processed by full-wave rectification. Data were stored using the Biopac student lab PRO 3.7.1 (Biopac System, USA) program and were section-filtered from 30 to 500 Hz and filtered at 60 Hz to remove noise. The muscle activity signal evaluated in each muscle was processed as a root mean square value and then normalized as a percentage of the root mean square value of maximal voluntary isometric contraction (MVIC) (%MVIC). Evaluation of maximum voluntary isometric contraction was performed in the manual muscle strength testing position and was recorded as the root mean square value of each muscle measured when contracted for 5 seconds. The maximal voluntary isometric contraction was assessed three times, and the average value was calculated and used (Figure 3).

Fig. 3: Electrode placement

2.4 Statistical Analyses

The data collected in this study were analyzed using the Windows SPSS version 26.0 (SPSS Inc, Chicago, IL, USA) program. The general characteristics of the subjects were tested for homogeneity using an independent sample t-test. The collected data were tested for normality of variables through the Shapiro-Wilk test, and as a result of the test, all data were normally distributed, so a parametric test was adopted. To determine the effect of insole height on ankle muscle activity, one-way repeated ANOVA was performed. Mauchly's mauchly's sphericity test was satisfied ($p>0.05$), and univariate analysis and within-subject effect test were performed. Also, there was a difference between variables, so a post-hoc analysis was performed. The statistical significance level α was set at 0.05.

3 Results

The demographic statistics of a single group are shown in Table 1. Sixty subjects (gender: male 36, female 24; age: 23.52±1.82years; height: 170.17±7.67cm; weight: 65.45±13.29kg). Raised heel insoles showed a significant decrease in Tibialis Anterior, Peroneus Longus, and Peroneus Brevis muscle activity than no raised heel insole ($p<.05$). Additionally, as a result of post-hoc analysis, there were significant differences in no raised heel insole, insole heights of 3cm, and insole heights of 7cm in the Tibialis Anterior and Peroneus Longus muscles ($p<.05$). There was a significant difference between the no raised heel insole and the raised heel insole in the Peroneus

Brevis muscle ($p<.05$), but there was no difference according to height ($p>.05$).

Table 1. General characteristics of subjects

	Group (N=60)
Gender (M/F)	36/24
Age (year)	23.52±1.82
Height (cm)	170.17±7.67
Weight (kg)	65.45±13.29

Mean±SD: Mean±Standard Deviation
**p<.05*

Table 2. Comparison of the ankle muscle activity between the no-raised heel insole and the raised heel insole

MVIC%	None[a] (Mean±SD)	3cm[b] (Mean±SD)	7cm[c] (Mean±SD)	*p*	post-hoc
Tibialis Anterior	28.81±10.90	25.73±12.08	17.84±4.45	.001*	a > b > c
Peroneus Longus	54.83±15.15	39.42±9.81	35.68±9.08	.000*	a > b > c
Peroneus Brevis	17.12±6.77	12.94±4.58	12.68±4.61	.037*	a > b,c
Gastrocnemius	49.86±11.73	57.47±6.59	68±6.49	.000*	c > b > a

Mean±SD: Mean±Standard Deviation
**p<.05*

Raised heel insoles showed a significant increase of Gastrocnemius muscle activity than no raised heel insole ($p<.05$). Additionally, as a result of post-hoc analysis, there were significant differences in no raised heel insole, insole heights of 3cm, and insole heights of 7cm in the Gastrocnemius muscle ($p<.05$) (Table 2).

4 Discussion

The shoes focus on the functional aspect to absorb shock to the foot during gait and ensure proper alignment of the body. However, with the recent emphasis on cosmetic aspects and increasing the heel or insole of shoes, the risk of musculoskeletal diseases such as ankle sprains is increasing, [15]. Accordingly, this study was conducted in normal adults to provide an ankle sudden inversion situation, which is a mechanical situation of actual ankle joint damage, and to determine the effect of raised heel insole on ankle muscle activity. For this study, insoles with no raised heel insole, insole heights of 3cm, and insole heights of 7cm were randomly applied to each subject. Then, standing on the trap door, a sudden ankle inversion was performed. The hypothesis of this study is that during ankle sudden inversion, ankle muscle activity decreases as the insole increases, causing ankle instability and having a negative effect in terms of prevention.

As a result of this study, the muscle activity of the tibialis anterior significantly decreased by 28.81±10.90% in the no-raised heel insole, 25.73±12.08% in the insole heights of 3cm, and 17.84±4.45% in the insole heights of 7cm. In addition, peroneus longus was significantly decreased to 54.83±15.15% in no raised heel insole, 39.42±9.81% in insole heights of 3cm, and 35.68±9.08% in insole heights of 7cm. These findings suggest that the higher the height of the insole, the muscle activity of the ankle muscles in the situation of the ankle sudden inversion. I think this is the cause of not properly protecting the ankle.

According to previous studies, tibialis anterior is the agonist of the ankle dorsiflexion, and peroneus longus is the agonist of the ankle eversion. In other words, the tibialis anterior and peroneus longus are muscles that protect the ankle joint and prevent damage when the ankle sprains in the inversion and plantarflexion, [16]. To prevent and protect ankle sprains, wearing raised heel insoles should be limited. Wearing of the raised heel insole must be limited to allow the tibialis anterior and peroneus longus to function normally. As the ankle plantar flexion angle increases, the risk of ankle sprains increases, [17]. In addition, high heel insoles move the center of gravity forward, negatively affecting balance and gait, [18].

As a result of this study, the muscle activity of the peroneus brevis decreased as the height of the insole increased. However, there was no difference in muscle activity between the insole height of 3cm and 7cm. It is thought that it was difficult to selectively record electrical activity in peroneus brevis using surface electrodes. In other words, the peroneus brevis is a synergist of the peroneus longus, and it is believed that it does not have a significant effect on ankle stability during sudden ankle inversion compared to the peroneus longus, [19].

As a result of this study, the muscle activity of Gastrocnemius significantly increased to 49.86±11.73% at no raised heel insole, 57.47±6.59% at insole heights of 3cm, and 68±6.49% at insole heights of 7cm. These research results are because Gastrocnemius is an agonist of ankle plantar flexion, and as the heel insole increases, the ankle plantar flexion angle increases. According to previous research, as the insole height increases, the ankle joint uses plantar flexion to adapt the body to the high heel insole, which is consistent with the research results showing that gastrocnemius contraction increases, [20]. Additionally, muscle activity of Gastrocnemius was significantly higher with eyes closed than with eyes open between no raised heel insole and insole heights of 7cm. These results were consistent with research results showing that when visual cue deprivation occurs, the demand for muscle contraction to maintain balance increases, [21]. In addition, the gastrocnemius provides ankle stability in static situations, but it is consistent with the research results that reported that the dorsiflexion strength is reduced and the risk of ankle sprain is greater when the gastrocnemius responds quickly, [22]. These results provide insight into the injury mechanism and causes of injury, and thus improve the existing preventive appliances.

Limitations of this study include that the age was limited to those in their 20s and only removable insoles were applied. In future studies, it is necessary to compare fixed insoles as well as removable height-elevating insoles with adults of various ages or patients with ankle instability. Additionally, it is believed that further research should be conducted on kinematic analysis and injury factors in ankle sudden inversion during gait, [23].

5 Conclusion

To summarize the results of this study, a raised heel insole increases the risk of ankle sprain injury by reducing tibialis anterior and peroneus muscle activity during ankle sudden inversion. Although a raised heel insole may be helpful in cosmetic aspects, the load generated during repeated gaits has a negative effect on the ankle joint. In other words, scientific evidence can be provided that raised heel insoles can increase the risk of injury in normal adults. It may also contribute to ankle joint damage prevention. This is expected to reduce treatment costs due to damage and reduce social expenditures such as medical expenses.

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- JongSung Chang has organized and executed the experiments.
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Conflict of Interest

The authors have no conflicts of interest to declare.