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The lower-extremity muscle co-activation of flat-footed subjects wearing high-heels while descending stairs.

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평발 대상자가 하이힐을 신고 계단을 내려갈 때 하지의 근활성도 변화

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Abstract The purpose of this study was to examine the lower-extremity muscle activation of flat-footed and normal-footed subjects descending stairs while wearing high-heels, thereby identifying any imbalance between the medial and lateral muscles.Thirty female students volunteered to participate in this study. The navicular drop test (NDT) was applied to the selection criteria for the flat-footed group and the normal-footed group. Surface electromyographic data was collected from the medial and lateral quadriceps, hamstrings, and gastrocnemius. Activation of MG and LG was significantly lower in the flat-footed group than in the normal-footed group. Both groups showed significant increases in MQMH and MHMG, but the co-activation in the medial and lateral muscles was lower in the flat-footed group. The co-activation ratios showed a significantly greater MQMH/LQLH in the flat-footed group. Flat-footed subjects who wear high-heels are more likely to experience impaired knee joint alignment than normal-footed subjects. Therefore, flat-footed subjects should use caution when descending stairs while wearing high-heels.

Key Words : Flat-foot, descending stairs, high-heel, muscle co-activation, EMG

요 약 본 논문의 평발인 대상자가 하이힐을 신고 계단을 내려갈 때 하지의 근활성도 변화를 알아보고자 한다. 이 연구의 대상자는 30명의 여학생으로 구성되어 있다. NDT를 이용하여 평발군과 정상군을 구분하였으며 표전근전도를 사용해 측정하였다. MG와 LG근활성도와 안, 가쪽 근공동활성도는 평발군에서 낮게 나타났고 근활성도 비율은 평발군이 안쪽에서 더 높게 나타났다. 그러므로 하이힐을 신은 평발군은 정상군보다 무릎관절 정렬에 더 많은 손상을 가질 가능성이 더 높으므로 계단을 내려갈 때 더 많은 주의가 필요할 것이다.

주제어 : 평발, 계단 내려가기, 하이힐, 근육공동활성화, 근전도

1. Introduction

Biomechanical functions of the foot are primarily propulsion, absorbing shock, and providing posture stability during walking(Abboud, et al., 2002; Perry, 1994). foot problems are related to impaired mobility and postural stability, which have a detrimental impact on quality of life(P.Kaoulla, et al., 2011; K.J. Gorter, et

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al, 2000; H.B. Menz, et al, 2006). Flat foot might be characterized as a mechanical imbalance by a decrease in the medial arch height and medial rotation of the talus. Flat foot is often accompanied by pain and frequently affects walking speed and balance, which increases the risk of falls(H.B. Menz, et al, 2006; J.M. Frances, et al, 2015; C.A. Demetracopoulos, et al, 2015).

Literature showed that wearing high heels can produce injurious effects on musculoskeletal system(J. Yu, et al, 2008; K.A. Opila-Correia, 1990). affecting structures from the toes to the pelvis. Wearing high heels leads to alterations in balance, regardless of the height of the heel (A. Mika, et al, 2016). Indeed, compared with barefoot, heels are responsible of difficulties in maintaining balance and enhanced risk of falls because of the changes of the center of mass and the decrease of the base of support (H.-L. Chien, et al, 2014; V. Dewi Hapsari, et al, 2016).

As can be seen, when an individual with flat feet, which cause changes in foot and ankle alignment, descends stairs wearing high-heels, it is likely to cause an imbalance in the muscles that maintain ankle joint stability. Therefore, the purpose of this study was to examine the lower-extremity muscle activation of flat-footed and normal-footed subjects descending stairs while wearing high-heels, thereby identifying any imbalance in the medial and lateral muscle co-activation.

2. Methods

2.1 Subjects

This study included 30 women in their 20s, none of whom had any medical history related to neurological problems. There were 15 flat-footed and 15 normal-footed women volunteering in the study. The navicular drop test (NDT) was applied to the selection criteria for the flat-footed group and the normal-footed group. Subjects with 0.8mm or above were assigned to the flat-footed group and those below 0.8mm were assigned to the normal-footed group. Table 1 This study received ethics approval from the Human Research Ethics Committee of Silla University (1041449-201605-HR-001)

Table 1. General characteristics of the subjects (Mean±SD) (N=30)

	Flatfoot group	Normal group	p
Navicular drop test(mm)	0.93±0.07	0.58±0.1	0.00
Age(years)	20.40±0.83	20.67±0.62	0.33
Body weight(kg)	56.60±8.23	54.93±6.56	0.55
BMI(kg/m^2)	22.48±2.33	21.53±1.37	0.42
Height(cm)	158.53±3.74	159.73±4.85	0.45
Foot length(mm)	239±6.04	236.67±5.23	0.27

Mean ± 1 Standard Deviation (SD)

2.2 Instruments

A wireless surface electromyography (EMG) device (4D-SES, RELIVE, Korea) was used to measure the lower-extremity muscle activation during stair descent. The sampling rate was 1000Hz, and the filter was a band-pass filter of 25-500Hz anda notch filter of 60Hz. The EMG data was collected from the medial and lateral quadriceps (MQ, LQ), hamstrings (MH, LH), and gastrocnemius (MG, LG). The reference electrode was placed on the patella. The EMG data was analyzed using the RELIVE EMG software (4D-SES, RELIVE, Korea).

All 30 subjects used high-heels that were 7cm in height and 235mm or 245mm in length. A study reported that the most comfortableheel height during regular walking is in the range of 3 to 5cm (Chun and Choi, 2000), so in this regard this study selected a heel height of 7cm to increase the weight bearing on the feet. In this study, two flights of stairs without any railings were used. The first was 60cm wide with 20cm risers and 28cm treads, and the second was 60cm wide with 20cm risers and 90cm treads.

2.3 Procedure

The navicular drop test (NDT) used in this study to identify flatfeet was introduced in a study by Brody(Brody, 1982) and indicates changes in the sagittal plane while loads are imposed. It has high reliability in evaluating navicular height (Sell, et al., 1994). The NDT was performed after a mark was put on the navicular tuberosity. Two raters derived the NDT value of each individual by subtracting the value measured with weight bearing on a foot from the value measured without weight bearing on the same foot. Each rater performed this step three times. The raters did not share the results of their measurement to increase reliability. In the NDT, the interclass correlation coefficient (ICC) as an estimate of intra-rater reliability was 0.973, and the ICC as an estimate of inter-rater reliability was 0.947. Both were statistically significant with a p-value of 0.000 for both.

Maximal voluntary isometric contraction (MVIC) was recorded to normalize the EMG data. MVIC was recorded for five seconds, and data was calculated from the middle threeseconds. For the quadriceps femoris, the subjects were instructed to maintain knee extension while sitting in a chair and then perform muscle contraction. For the hamstring, the subjects were instructed to maintain knee flexion in a prone position and then perform muscle contraction. For the gastrocnemius, the subjects were instructed to fix their body by holding a table in a standing position and then perform muscle contraction by pushing themselves up with their toes(Peterson-Kendall, et al., 2005).

Two or three times, dead skin cells were removed through rubbing the areas to which the electrodes would be attached, and this was done by using a disposable razor to minimize skin resistance to the surface EMG signals. Skin fat was then removed using cotton balls and rubbing alcohol, and then the electrodes were attached.

Muscle activation was measured during the stair descent task. Subjects stood on the second stair with both feet parallel and pelvic-width apart. Upon the first step, the measurement foot was descended tothe first floor, then the second step non-measurement foot was descended to the ground at a self-comfortable speed. Fig. 1 We measured the muscle activation of the first step for both groups. This stair descent task was repeated five times with a 30-second rest between tasks.

Fig. 1. measured during the stair descent

2.4 Data analysis

Muscle cocontraction was assessed between the MQ and MH, between LQ and LH, between MH and MG, between LH and LG. Cocontraction was determined using the equation described by EMGS/EMGL*(EMGS+EMGL), where EMGS was the level of activity in the less active muscle and EMGL was the level of activity in the more active muscle. The index was multiplied by the sum of the activity found in the 2 muscles. We calculated the ratio of lateral-to-medial co-contraction by dividing the lateral H:G co-contraction index by the Medial H:G co-contraction index(Palmieri-smith et al., 2009). The study compared the muscle activation, co-activation, and co-activation ratios during stair descent between the two groups. The ICC (2, 1) was measured to examine intra-rater reliability (Cote, et al., 2005; Vicenzino, et al., 2005). The independent t-test was performed to compare differences in the lower-extremity muscle activation of the flat-footed group and normal-footed group during stair descent. The statistical significance level was set at $\alpha=0.5$, and the software package SPSS version 24.0 was used for statistical processing.

3. Results

In this study, the flat-footed group showed a statistically significant lower level of muscle activation in the gastrocnemius than the normal-footed group (P<0.05). The lateral quadriceps showed a higher level of muscle activation in the flat-footed group. The medial hamstring showed a higher level of muscle activation in the normal-footed group (P<0.05). Table 2.

Table 2. Comparison of the muscle activation during stair descent between the two groups

	Flatfoot group	Normal group	T	p
MQ	41.34±3.41	42.98±4.95	-1.056	0.300
LQ	50.26±5.69	42.74±6.26	3.446	0.002
MH	38.00±2.14	42.06±4.88	-2.948	0.006
LH	33.37±5.74	36.44±3.36	-1.789	0.084
MG	46.29±3.40	49.76±3.65	-2.693	0.012
LG	36.92±6.83	42.01±3.94	-2.499	0.019

Mean ± 1 Standard Deviation (SD)
MQ: Medial Quadriceps,LQ: Lateral Quadriceps,
MH: Medial Hamstring, LH: Lateral Hamstring
MG: Medial Gastrocnemius, LG: Lateral Gastrocnemius

Comparison of the muscle co-activation during stair descent between the two groups

In this study, both groups showed higher levels of muscle co-activation in the medial muscles in terms of the MQMH, LQLH, MHMG, and LHLG, while the flat-footed group showed lower levels of muscle co-activation in the medial and lateral muscles compared to the normal-footed group (P<0.05). Table 3.

Table 3. Comparison of the muscle co-activation during stair descent between the two groups

	Flatfoot group	Normal group	t	p
MQMH	71.24±4.98	78.45±10.24	-2.453	0.021
LQLH	56.11±13.22	67.64±6.44	-3.036	0.005
MHMG	67.70±4.28	76.27±10.16	-3.012	0.005
LHLG	60.14±9.93	68.42±9.43	-2.341	0.027

Mean ± 1 Standard Deviation (SD)
MQMH: Medial Quadriceps Medial Hamstring,
LQLH: Lateral Quadriceps Lateral Hamstring
MHMG: Medial Hamstring Medial Gastrocnemius,
LHLG: Lateral Hamstring Lateral Gastrocnemius

Comparison of the muscle co-activation ratios during stair descent between the two groups

The flat-footed group showed lower LQLH/MQMH and LHLG/MHMG ratios compared to the normal-footed group. Fig. 2

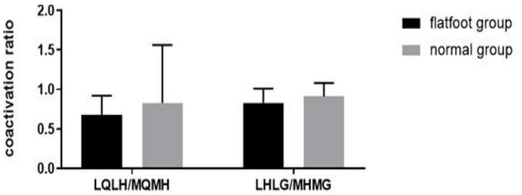

Fig. 2. Comparison of the muscle co-activation ratios during stair descent between the two groups

4. Discussion

The comparison of the muscle activation during stair descent between the two groups showed that the flat-footed group had statistically significant lower levels of muscle activation in the gastrocnemius compared to the normal-footed group. The comparison of the two groups during stair descent showed that both groups had higher levels of muscle co-activation on the medial side in the Q:H co-activation and H: G co-activation. For the H: G co-activation, the flat-footed group exhibited a higher level of muscle co-activation on the medial side compared to the normal-footed group.

In this study, the flat-footed group showed an overall lower level of muscle activation in the gastrocnemius than the normal-footed group, and this was statistically significant. The subjects wore 7cm high-heels, creating a position that shortened the length of the gastrocnemius (Peterson-Kendall, et al., 2005). As a result, the length-tension relationship that could enable the gastrocnemius to generate greater force was not formed, and thus, muscle contraction was reduced(K. H. Lee, et al., 1990). In addition, considering that the flat-footed group showed lower muscle activation than the normal-footed group, the lowered medial longitudinal arch in a flat foot may have further increased plantar flexion, thereby further shortening the length of the gastrocnemius. moreover the pes planus foot will exhibit excessive dorsiflexion of the midfoot, especially late in stance (Franco, 1987; Olsen and Saidei, 1983). Therefore, muscle activity decreased because the gastrocnemius muscles relaxed by dorsifoxion of midfoot.

In this study, both groups showed higher levels of muscle co-activation in the medial muscles in terms of medial and lateral muscle co-activation of the MQMH, LQLH, MHMG, and LHLG, and the flat-footed group exhibited lower levels of medial and lateral muscle co-activation than the normal-footed group.

Muscular co-activation is a well-known mechanism for lower limb joint stabilization in both healthy and pathological individuals. This muscular feature appears particularly important for the knee joint(Alessandro Menarelli. et al., 2018). The flat-footed group exhibited an internal rotation of the tibia due to a loss of the medial longitudinal arch. This forms the movement of knee valgus that could change a normal kinematic mechanism (Neumann, 2010).

Therefore, during the stair descent of flat-footed subjects in high-heels, the medial knee muscles limited the movement of knee varus through their greater muscle activation to control ankle instability against pronation (Palastanga, et al., 2006). The level of experience is associated with perception which influences the level of coactivation (Marras et al., 2006). Inexperienced people tend to be more rigid during task execution, which impedes upon the functional synergy needed for fluidic motion (Bernstein, 1967). Whereas, for experienced workers, motor patterns cooperate more optimally to execute the task (Magill, 2004). Overall, coactivation is influenced by the level of experience(Peter Le et al., 2016). But in this study participated young women are not accustomed to wearing high-heeled. In addition Wearing High-heeled shoes puts the foot and ankle joints in an unstable position resulting in reduced shock absorption due to the smaller supporting bases (Srivastava et al., 2012). Therefore, the overall lower muscle activation shown in the flat-footed group may suggest that a flat foot experiences more inversion than the normal foot due to a loss of the medial longitudinal arch, and thus is limited in the movement of knee varus in regard to lower muscle activation.

Both groups recorded less than 1 in the LQLH/MQMH and LHLG/MHMG ratios. This means that the co-activation of the medial muscles was greater than that of the lateral muscles. In addition, the flat-footed group's lower values indicate that the flat-footed group experienced larger co-activation in the medial muscles than the lateral ones. The co-contraction of the muscles around the knee joint helps maintain joint stability and balance through a balanced activation of the medial and lateral or anterior and posterior sides. However, muscle activation with imbalanced co-contraction can disturb knee joint alignment (Markolf, et al., 1995). Therefore, a flat foot with a larger imbalance between the left and right sides may involve a higher risk of disrupting knee joint alignment.

5. Conclusion

Both groups showed higher levels of muscle activation and co-activation in the medial muscles than the lateral ones while descending stairs while wearing high-heels, and the flat-footed group exhibited higher co-activation ratios in the medial muscles than in the lateral ones. Accordingly, when flat-footed subjects wear high-heels, they can suffer damage to their medial knee joints because of greater activation in the medial knee muscles.

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