The Effects of Lower Extremity Angle According to Heel-height Changes in Young Ladies in Their 20s during Gait

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Abstract. [Purpose] The purpose of this study was to compare the effects of heel-height changes on the low joint angles of the lower extremities of women in their 20s during gait. [Subjects and Methods] Qualisys Track Manager Software ver. 2.8 (Qualisys, Sweden) was used to perform measurements on 14 female university students in their 20s. To measure movements, the subjects were asked to walk while wearing high-heeled shoes and reflective stick- ers on their hip joints, knee joints, and ankle joints, the changes in joint angles were measured at heel strike, foot flat, and toe off. [Results] Analysis of the amount of change according to heel height changes during gait showed that the angle of the hip joints was reduced with an increase in heel-height. Although the changes were not significant, the angle of the knee joints was reduced during heel strike, foot flat, and midstance, and it was increased during toe off. In contrast, the angle of the ankle joints was increased by a significant amount during heel strike, foot flat, midstance, and toe off. [Conclusions] During gait with high heels, the movements of the lower extremities of women in their 20s were reduced significantly with an increase in heel height. Therefore, it is concluded that the restrictions on gait can only be reduced by wearing low-heeled shoes.

Key words: Heel height, Gait, Low extremity

INTRODUCTION

Human beings have walked as a means of movement for a long time1). But as such movements always cause external shocks and stimulations, human beings have worn footwear or shoes, which absorb the shock loadings created during gait, to protect various joints2). In particular, in contemporary society, the aesthetic aspects of shoes are far more emphasized than their functional aspects, and in the case of women, high-heeled shoes are more preferred3). It is known that the shoes preferred by modern generations due their aesthetics, with sharp front sections and pointed and high heels, cause many disorders and are the causes of serious functional disabilities for women wearing high-heeled shoes4).

Wearing high-heeled shoes for an extended period of time causes ankle joint sprains and excessive plantar bending due to increases in vertical shock loadings and brings about postural changes by concentrating the weight distribution to the front5). Gefen et al.6) reported that the shock loadings and instability are increased at the instant of heel contact in the stance phase and generate changes in the dynamic biomechanics of foot: a motion analysis system was used to do their research. During gait, the rise in energy consumption and intensification of muscle fatigue lead to imbalance of the muscles that maintain the stability of the ankle joints7). Lee et al.8) reported that the higher the heel heights of their subjects, female university students, the higher the occurrences of foot-related disorders, as various parts of the foot are affected. Additionally the worsened gait conditions and center-of-gravity instability bring about fatigue that is caused by the imbalance of each body part and an increase in energy consumption. Nyska et al.9) reported that during gait, shoes with a high heel put more load on the front parts of the foot than shoes with low heel heights. Franklin et al.10) reported that when wearing high-heeled shoes, the lumbar sacral lipoma angle, pelvis front view, and lumbar lordosis angle decreased significantly compared with the barefoot values. In addition, Kim et al.4) illustrated that the lumbar lordosis angle of women in their 20s increased significantly when wearing shoes with a higher heel height. Andrew et al.11) reported that high-heel shoes cause back pain. Snow et al.12) reported that wearing high-heeled shoes for an extended period of time brings about kinematics and dynamics changes to compensate for the changes in the locations of body parts and the center of gravity.

Previous researches, some researches on causes of abnormalities in the legs and the changes in joint functions resulting from lumbar sacral lipoma have been performed, but only limited research has been performed regarding analysis of lower extremity angles for different heel heights.
of shoes. The heel heights of shoes worn by women in contemporary society have positive influences on aesthetics but restrict joint movements from a gait perspective. Therefore, the aim of this study was to find out what effects changes in shoe heel height have on gait by analyzing the changes in lower extremity angle during gait.

SUBJECTS AND METHODS

Subjects

Fourteen subjects were chosen from female students attending N University, Cheonan, Republic of Korea. The criteria used to select the 14 subjects were as follows: individuals who had no significant foot deformity or corns, had never had any surgery, fully understood the purpose of this study, and willingly agreed to participate in this study. This study was approved by the Korea Nazarene University Institutional Review Board and was conducted in accordance with the ethical principles of the Declaration of Helsinki. The general characteristics of the subjects who participated in this study are summarized in Table 1.

Methods

All subjects were examined while wearing shoes with each of the following heel height: 3 cm, 5 cm, and 7 cm. Heel height is the difference between the heights of the heel and front sections of a shoe and identical pairs of shoes were purchased and used in the study. Qualisys Track Manager Software ver. 2.8 (Qualisys AB, Sweden) was used to measure and analyze movement. Six high-speed digital cameras (Qualisys ProReflex system, 240 Hz) that operate at 100 Hz per second were installed on subjects to obtain kinematics information for their legs during high-heeled gait.

In order to establish a coordinate system for the whole area, a reference point of the space in which the movements would be carried out was defined by placing an L-shaped frame with 4 markers of predetermined lengths on the floor. A right-handed Cartesian coordinate system was employed: the upward direction vertical axis was +Z, the direction of movement axis was +Y, the cross form +Y axis to the +Z axis +X. The local coordinate systems established for the thigh, lower leg, and foot of the right segments were the same as the whole area coordinate axis. All subjects wore short sleeve shirts and tights. In order to track the 3D movements of the 3 segments of the legs of the subjects, reflector markers, consisting of 3 nonlinears, were attached to the sides of the hip joint, knee joint, and ankle joint, on the cap of the high-heeled shoe for the foot segment, and the surface corresponding to the 5 mesopodium articular head, in the mid sections of ankle and knee joints. In addition, a marker was attached on the toe section of the high-heeled shoe in order to verify toe off in the stance phase during gait. The subjects went through gait exercises so they could maintain a natural smooth gait and their normal walking speed. Gait was performed wearing shoes with heel heights of 3 cm, 5 cm, and 7 cm. In the analysis of lower extremity angle, the support phase of the right foot was set as the time between heel strike and toe off (13). Prior to taking the gait pictures, reference directions were set for the leg segments of each subject, and the standing calibration was used for each condition in order to reduce the possibility of the reflective markers not being accurately placed anatomically on the subjects. After lining up the long axis of the foot on the front and back axes of the whole area coordinate system, the position was filmed for 3 seconds.

Data processing in this study was performed using SPSS 12.0 for Windows. The general characteristics of the subjects were expressed using mean values, standard deviations, and percentages. Repeated measures ANOVA was performed to analyze the changes in low extremity angle according to each heel height of a subject, and the LSD was used to perform a post analysis to show the difference according to each posture. The value for α, a level of statistical significance, was set at 0.05.

RESULTS

When the changes in the hip joint angles during gait were compared according to the heel-height changes of the subjects, they were found to have increased during heel strike, foot flat, midstance, and toe off according to changes in shoe heel height, but only by insignificant amounts (p>0.05) (Table 2).

When the changes in the knee joint angles during gait were compared according to the heel-height changes of the subjects, they were found to have increased during heel strike, foot flat, and midstance according to the changes in shoe heel height and to have decreased during toe off, but only by insignificant amounts (p>0.05) (Table 3).

When the changes in the ankle joint angles during gait were compared according to the heel-height changes of the subjects, they were found to have decreased significantly (p<0.05) during heel strike, foot flat, and midstance and toe off according to the changes in shoe heel height: significant differences were found during all phases of heel strike, foot flat, and midstance (p<0.05), and significant differences were found in toe off between heel heights of 3 cm and 7 cm and between heel heights of 5 cm and 7 cm (Table 4).

DISCUSSION

High-heeled gaits induce changes in the soft tissues around the foot by increasing the shock loadings during static and dynamic movements and are considered to cause potentially damaging conditions such as deformations in the foot and ankle, weakening of muscles, and damages to ligaments and joints (14, 15). The body is affected greatly by these influences, and hence restricted leg movements dur-
ing gait are seen. As there was very little data available on the instability associated with restricted movements of the lower extremity resulting from wearing high-heeled shoes, the aim of this study was to investigate changes in the low extremity angles according to shoe heel heights, 3 cm, 5 cm, and 7 cm, during gait of women in their 20s. As shoes with heel heights of 3 cm, 5 cm, and 7 cm had been used in previous studies\(^{16,17}\), the present study used the same heel heights.

The results of comparing the low extremity angles according to the changes in shoe heel height showed decreases in the hip joint angles, knee joint angles, and ankle joint angles, but the decrease in the joint angle was more significant than the others. Wearing high-heeled shoes during gait raises the center of gravity of the human body. This brings about instability in the upright position, and this becomes more pronounced during gait. Therefore, the drop in stability during gait is thought to lead to significant drops in the balance issue and mobility of the low extremity that causes gait.

Kerrigan et al.\(^{18}\) remarked that wearing high-heeled shoes during gait, which causes weight to shift towards the inner side of the feet, cause a degenerative deformation inside, rather than outside, the knee joints. Also, during high-heeled gait, compensatory actions take place in knee joints and hip joints to make up for the reduction in stability. Sussman and D’Amico\(^{19}\) remarked that in the cases of the left and right ankles, as the heel height is raised, plantar flexions of the ankle joints increase, and more pressure is applied to the foot, which changes the locations of bones within joints and the application angles of muscles. Kim and Park\(^{20}\) stated that wearing high-heeled shoes for an extended period of time applies stress to bar, and the changes in the center of gravity of the human body not only bring about changes in body alignment but also affects the gait and leg functions negatively. Hyen et al.\(^{21}\) remarked that fatigue can be readily induced according to heel height and recommended a heel height of 4 cm. Lee and Jung\(^{22}\) remarked that the higher the heel height and the smaller the cross-sectional area of the heel that comes in contact with the ground, the greater the effect the heel height has on the movements of the center of human body and waist muscles and the loads on the legs. They also remarked that an increase in heel height not only causes changes in muscle loads but also brings about increases the changes in center of gravity of the human body, in both the vertical and horizontal directions, and leads to unstable gait postures. Ryu\(^{23}\) reported that due to their structural characteristics, high-heeled shoes aggravate the discomfort of gait and affect negatively not only the stability of the whole body stability but also local stabilities by affecting the foot and ankles. Simonsen et al.\(^{24}\) remarked that high heels cause the plantar curve angle to increase and hence the dorsiflexion angle to decrease. Yeo\(^{25}\) reported that shoes with heel

| Table 2. Comparison of hip joint angles according to heel-height changes |
|-----------------------------|-----------|-----------|-----------|
| Motion                      | 3 cm      | 5 cm      | 7 cm      |
| Heel strike (°)             | 25.7 ± 6.0| 26.2 ± 6.5| 27.1 ± 6.5|
| Foot flat (°)               | 21.3 ± 7.7| 21.4 ± 6.6| 23.8 ± 8.3|
| Midstance (°)               | 9.4 ± 8.2 | 9.8 ± 7.4 | 11.4 ± 8.4|
| Toe off (°)                 | 7.3 ± 7.9 | 6.8 ± 12.1| 8.0 ± 7.6 |

Mean±SD; *p<0.05

| Table 3. Comparison of knee joint angles according to heel-height changes |
|-----------------------------|-----------|-----------|-----------|
| Motion                      | 3 cm      | 5 cm      | 7 cm      |
| Heel strike (°)             | −14.3 ± 6.8| −14.7 ± 7.8| −15.6 ± 6.1|
| Foot flat (°)               | −19.7 ± 6.7| −20.3 ± 8.3| −22.0 ± 7.4|
| Midstance (°)               | −16.3 ± 5.7| −17.7 ± 7.2| −18.6 ± 6.5|
| Toe off (°)                 | −58.9 ± 7.2| −53.8 ± 7.3| −54.6 ± 6.7|

Mean±SD; *p<0.05

| Table 4. Comparison of ankle joint angles according to heel-height changes |
|-----------------------------|-----------|-----------|-----------|
| Motion                      | 3 cm      | 5 cm      | 7 cm      |
| Heel strike (°)*            | 68.4 ± 3.2| 62.9 ± 4.1| 53.4 ± 4.5\(^{abc}\)|
| Foot flat (°)*              | 65.7 ± 2.7| 62.3 ± 4.9| 52.5 ± 6.3\(^{ab}\)|
| Midstance (°)*              | 72.7 ± 3.4| 69.5 ± 3.5| 59.5 ± 5.4\(^{abc}\)|
| Toe off (°)*                | 65.7 ± 3.9| 63.0 ± 5.5| 57.3 ± 7.2\(^{bc}\)|

Values are means ± SD; *p<0.05; \(^a\) Significant difference between 3 cm and 5 cm, \(^b\) Significant difference between 3 cm and 7 cm, \(^c\) Significant difference between 5 cm and 7 cm
heights 2–3 cm are most preferred by women and that this is because they experience the least amount of fatigue and feel comfortable during gait. This present study reached the same conclusion as made in various previous studies: an increase in shoe heel height brings about restricted leg movements, while wearing low-heeled shoes brings about recovery of gait abilities.

Thus, it is concluded that when women in their 20s wear shoes, wearing high-heeled shoes can impose significant restrictions during gait. Therefore, movements during gait can be reduced if low-heeled shoes are worn. More research based on the data in the present study is needed regarding the overall kinematics of the legs through comprehensive measurements such as motion analysis of trunk muscles and lower leg muscles and gait analysis according to shoe heel height in women in their 20s.

ACKNOWLEDGEMENT

This work was supported by the University Research Grant of the Korean Nazarene University in 2014.

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