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The Change of Plantar Pressure According to the Height of Heel Lifts in Obese and Non-Obese Adults

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Abstract

The purpose of this study was to assess the peak plantar pressure distribution under foot areas according to the height of heel lifts in obese adults and non-obese adults during walking. Thirty-one participants volunteered for this experiment. The average body mass index (BMI) value of the fourteen subjects in the obese group was 26.5±1.4 ㎏/㎡ (from 25.1 to 29.3 ㎏/㎡), and of seventeen subjects in the non-obese group was 20.0±1.1 ㎏/㎡ (from 18.7 to 22.7 ㎏/㎡). The subject ambulated while walking in the sneakers, walking with 2 ㎝ heel lifts, and walking with 4 ㎝ heel lifts in the shoes. We measured the peak plantar pressure under the hallux, 1st, 2nd, 3~4th, and 5th metatarsal head (MTH), mid foot, and heel using F-scan system. The obese group had significantly higher peak plantar pressure under all foot areas than the non-obese group regardless of the height of heel lifts ($p<.05$). The peak plantar pressure under the 5th MTH and heel was significantly decreased, also the peak plantar pressure under hallux, 1st, and 2nd MTH was significantly increased according to the height of heel lifts in the obese group and non-obese group ($p<.05$). We proposed that individuals with heel lifts in shoes should be careful, as there is high plantar pressure under the forefoot.

Key Words: Heel lifts; Obesity; Plantar pressure.

Introduction

Obesity is a serious health problem worldwide and the prevalence of obesity is increasing rapidly (Birtane and Tuna, 2004). Obesity significantly increases the risk of developing many medical conditions, including hypertension, stroke, respiratory disease, diabetes mellitus, osteoarthritis, and various musculoskeletal disorders, particularly of the lower extremities and feet (James, 1995; Must and Strauss, 1999). Because the foot is a major part of the body that bears significant weight while standing and walking, many studies have investigated plantar pressure in obese subjects (Birtane and Tuna, 2004; Dowling et al, 2001; Hills et al, 2001; Hills et al, 2002; Spyropoulos et al, 1991). Hills et al (2002) reported that increased body weight would result in higher plantar pressures. High peak plantar pressures during walking can contribute to painful forefoot syndromes, including metatarsalgia and plantar ulceration (Actis et al, 2008).

Many young individuals use heel lifts in shoes to increase their height for cosmetic purposes, also clinicians may include placement of heel lifts in a patient's shoes as part of a comprehensive treatment for patients with overuse injuries associated with limited dorsiflexion (Johanson et al, 2006) and leg length discrepancy (Rancont, 2007). Limited ankle joint dorsiflexion has been associated with many overuse injuries of the lower extremity, including plantar fasciitis (Riddle et al, 2003), Achilles tendinitis (Kaufman et al, 1999; Warren and Davis, 1988), shin splints (Messier and Pittala, 1988), illiotibial band syndrome (Messier and Pittala, 1988), and pa-

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tellofemoral pain syndrome (Lun et al, 2004). Theoretically, heel lifts is a sagittal plane correction for ankle joint contracture, whereas forefoot and rearfoot posts and wedge are frontal plane corrections (Donatelli, 1996). Heel lifts increase ankle dorsiflexion excursion, increase time to heel off, and either increase or decrease the maximal amount of knee extension before heel off when ankle dorsiflexion is limited (Tiberio, 1987). Heel lifts reduces the need for compensatory pronation when the subtalar joint compensates for dorsiflexion limitation by pronating excessively, especially from heel rise through push-off (Donatelli, 1996). Johanson et al (2006) investigated the effects of heel lifts on ankle dorsiflexion excursion, maxiamal knee extension, and time to heel off during the stance phase of gait in subjects with limited dorsiflexion. There are some studies that the effectiveness of height of lateral or medial wedge on osteoarthritis patients (Toda and Tsukimura, 2006; Toda et al, 2004). Also, in studies on patients with metatarsalgia and rheumatoid arthritis it was found that a metatarsal dome or pad reduced forefoot peak pressures (Hodge et al, 1999; Holmes and Timmerman, 1990), and studies on the effects of wedges on plantar pressure reported significant reductions for forefoot area (Rose et al, 1992; Van Gheluwe and Dananberg, 2004). Previous some studies have demonstrated that walking in high-heeled shoes raises the peak pressure in the forefoot (Mandato and Nester, 1999; Snow et al, 1992), however, few studies have considered plantar pressure and heel lifts in shoes during walking.

Obese individuals may wear shoes with heel lifts for cosmetic reasons, or they may need heel lifts to increase ankle dorsiflexion. However, we have found no studies that have examined the relationship between plantar pressure and various height of heel lifts in obese individuals. The knowledge of peak plantar pressure affected by heel lifts may assist obese individuals who may have pain or discomfort of lower extremities and feet or relate to diabetic patients with neuropathic feet such as foot ulceration. The purpose of this study was to assess the peak plantar pressure distribution under foot areas according to the height of heel lifts in obese adults and non-obese adults during walking.

Methods

Subjects

Thirty-one study participants volunteered for this experiment. Subjects were college students in Daegu city. Subjects were excluded if they had foot pain or deformities, acute lower extremity trauma, lower extremity surgery, leg length discrepancies, diabetes, peripheral neuropathy, or vascular insufficiency. The purpose of the study was carefully explained to each subject and a comprehensive subject information package was provided at a session prior to the signing of an informed consent. For the males, body mass index (BMI) was 23.0±3.4 ㎏/㎡ and ranged from 19.2 to 29.1 ㎏/㎡. For the females, BMI was 22.6±3.8 ㎏/㎡ and ranged from 18.7 to 29.3 ㎏/㎡. The average BMI value of the fourteen subjects in the obese group was 26.5±1.4 ㎏/㎡ (from 25.1 to

Table 1. General characteristics of the subjects (N=31)

Subjects	Sex		Age (yrs)	Height (㎝)	Weight (㎏)	BMI[b]	Shoe size (㎜)
Non-obese group (n_1=17)	Male	9	26.3±2.1[a]	174.0±5.6	62.0±3.4	20.5±1.2	266.7±5.0
	Female	8	22.9±1.8	162.0±3.3	50.9±2.4	19.4±.8	239.3±5.0
Obese group (n_2=14)	Male	7	26.2±2.8	177.2±5.1	84.0±5.2	26.8±1.4	272.5±8.2
	Female	7	21.7±1.0	159.9±3.3	67.4±5.7	26.4±1.5	240.7±5.3

[a]Mean±SD.
[b]Body mass index.

29.3 kg/m²), and of seventeen subjects in the non-obese group was 20.0±1.1 kg/m² (from 18.7 to 22.7 kg/m²). A BMI of greater than or equal to 25 kg/m² was used to classify as obese (Dowling et al, 2001). General characteristics of the subjects are shown in Table 1.

Instruments

Plantar Foot Pressure Measurement

The plantar pressure distribution was measured using the F-Scan system[1] with an in-shoe sensor (Figure 1). This system measures plantar pressure in standing and walking. The F-Scan system consists of flexible in-shoe sensors, a transducer unit, cuff units, and a notebook computer. The in-shoe sensors were trimmed to fit a variety of shoe sizes without compromising function. Data were collected and processed with F-Scan research TAM/STEM Version 6.00 software (TekScan Inc., South Boston, MA, U.S.A.). Data acquisition was sampled at a frame rate of 30 Hz.

Sneakers and Heel Lifts

Sneakers were used in this study during walking. The shoes are comfortable and many individuals wear sneakers which became known popularly. The size of shoes ranged from 235 to 280 mm and the shoes were prepared at 5 mm intervals. The heel lifts were made of polyurethane. The size of the heel lifts was 6.3 cm wide, 14.5 cm long, and the heights of the two sizes were 2 and 4 cm (Figure 2).

Figure 1. Sneakers and F-Scan system.

1) TekScan Inc., South Boston, MA, U.S.A.

Procedure

All subjects were measured in three different experimental conditions (non-inserts, with 2 cm heel lifts, and with 4 cm heel lifts). An in-shoe pressure sensor was cut to fit the shoe of each subject, and the pressure sensor was placed in the shoes over the heel lift insert and under the plantar foot (Figure 1). The subjects walked around for 5 minutes in order to adapt to the new shoes. For data collection, the subjects were asked to walk in the sneakers, with 2 cm heel lifts in the shoes, and with 4 cm heel lifts in the shoes. The testing order for the three conditions was determined randomly using a prearranged schedule. The sensor was calibrated according to manufacturer's guidelines and the data was collected during 12 step walking trials. Three repetitive trials were performed in each experimental condition. Before recording each condition, the subjects repeated warm-up walking trials. Data from the right foot was processed and average values of peak plantar pressure were calculated under hallux, 1st metatarsal head (MTH), 2nd MTH, 3~4th MTH, 5th MTH, mid foot, and heel in each step.

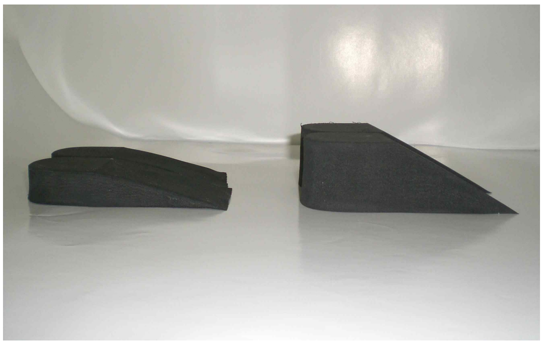

Figure 2. Heel lifts (Left: 2 cm, Right: 4 cm).

Statistical Analysis

Two-factor mixed factorial analysis of variance (ANOVA) design was used to examine the difference in peak plantar pressure of the under foot area for walking with non-inserts, 2 ㎝ heel lifts, and 4 ㎝ heel lifts between the non-obese group and obese group. The level of significance was set at p<.05. To assess statistically significant differences in each of the conditions, a Bonferroni's adjustment was performed. Statistical significance was defined at p<.017 (.05/3). The statistical analysis of data was performed using SPSS 11.5.

Results

The peak plantar pressure under the hallux, 1st, and 2nd MTH was significantly increased when walking with non-inserts, 2 ㎝ heel lifts, and 4 ㎝ heel lifts in the obese and non-obese group (p<.05) (Table 2). Significant between-group effects were evident in the peak plantar pressure under the hallux, 1st, and 2nd MTH (p<.05) (Table 3) (Figure 3).

The peak plantar pressure under the 5th MTH and heel was significantly decreased when walking with non-inserts, 2 ㎝ heel lifts, and 4 ㎝ heel lifts between the obese and non-obese group (p<.05) (Table 2). Significant between-group effects were evident in the peak plantar pressure under the 5th MTH and heel (p<.05) (Table 3) (Figure 3).

No significant difference in the peak plantar pressure under 3~4th MTH and mid foot was observed, although significant between-group effects were detected (p<.05) (Table 3) (Figure 3).

Discussion

Problems of obesity commonly cited include general discomfort in simple activities of daily living such as walking and stair-climbing, pain in the joints of the lower extremity, poor circulation including edema, and soreness or numbness in the feet during standing or walking (Hills et al, 2001). Most previous studies found that peak pressure increased in the heel, mid foot, and metatarsal regions both

Table 2. Comparison of the two-factor mixed factorial ANOVA performed on the data of peak plantar pressure in obese and non-obese group (N=31, unit: KPa)

		Type Ⅲ Sum of Squares	df	Mean Square	F	p
Hallux	height[a]	41122.863	1.531	26868.281	7.941	.003
	height × group	4139.146	1.531	2704.378	.799	.426
1st MTH[b]	height	95138.617	1.538	61851.654	12.759	.000
	height × group	5061.696	1.538	3290.717	.679	.475
2nd MTH	height	81996.376	2	40998.188	8.346	.001
	height × group	13758.501	2	6879.251	1.400	.255
3~4th MTH	height	20127.513	2	10063.756	1.855	.166
	height × group	8573.791	2	4286.895	.790	.459
5th MTH	height	43919.897	1.646	26680.925	10.230	.000
	height × group	10524.261	2	5262.130	2.451	.106
Mid foot	height	655.434	1.405	466.375	.838	.403
	height × group	52.779	1.405	37.555	.068	.874
Heel	height	128180.160	1.567	81825.257	41.414	.000
	height × group	3722.549	1.567	2376.332	1.203	.301

[a]Height of heel lifts.
[b]Metatarsal head.

Table 3. Tests of between-subjects effect on the data of peak plantar pressure in obese and non-obese group (N=31, unit: KPa)

	Type Ⅲ Sum of Squares	df	Mean Square	F	p
Hallux	421201.579	1	421201.579	28.478	.000
1st MTH[a]	78433.092	1	78433.092	4.249	.048
2nd MTH	514691.080	1	514691.080	8.450	.007
3~4th MTH	633122.918	1	633122.918	19.053	.000
5th MTH	100332.519	1	100332.519	14.519	.001
Mid foot	4498.187	1	4498.187	5.846	.022
Heel	107703.794	1	107703.794	16.831	.000

[a]Metatarsal head.

during standing and walking in obese subjects when compared to non-obese subjects (Birtane and Tuna, 2004; Dowling et al, 2001; Hills et al, 2002). However, the magnitude of the effect of obesity on plantar pressure has not been well investigated. Some authors reported different results of relations between BMI-weight and peak plantar pressure values (Hills et al, 2002). The major cause of this controversy may be the lack of standardization in the group of obese subjects. Birtane and Tuna (2004) investigated the effects of obesity on the plantar pressures using class 1 obesity of BMI values between 30 and 34.9 ㎏/㎡ and reported increased peak plantar pressure in only under the middle foot during walking. Hills et al (2001) evaluated obese subjects in a wide range of BMI, between 17.1 and 55.8 ㎏/㎡ and reported higher peak plantar pressure in under the hallux, 2nd, 3rd, 4th, and 5th MTH, mid foot, and heel for men group and under all MTH and mid foot for women. Dowling et al (2001) examined the effects of obesity on plantar pressure in 13 obese children (BMI: 25.5±2.9 ㎏/㎡) and the obese children generated significantly higher plantar pressures under the forefoot during walking. In this study, BMI values of the subjects were ranged from 25.1 to 29.3 ㎏/㎡ in the obese group and the obese group had significantly higher peak plantar pressure under all foot areas than the non-obese group regardless of the height of heel lifts. These results are in accordance with those of Hills et al (2001) however, discrepancies exist regarding mid foot pressures. Peak plantar pressure under the mid foot showed the highest excursion of values between the obese and non-obese group in the studies of Britane and Tuna (2004) and Hills et al (2001). In this study, the peak plantar pressure under the mid foot showed little excursion, though significant between-group effects were detected, perhaps because of the lower grade of obesity in our population. Excessive weight bearing due to obesity is believed to cause structural foot dysfunction, such as collapse of the longitudinal arch, which leads to increased middle foot contact area (Riddiford-Harland et al, 2000).

Increasing ankle dorsiflexion excursion by using heel lifts may also reduce compensatory dorsiflexion at the subtalar and midtarsal joints related to restricted dorsiflexion at the talocrural joint (Donatelli, 1996). A few studies have demonstrated that walking in high-heeled shoes shifts peak pressures from the 3rd, 4th and 5th metatarsal heads to the 1st and 2nd metatarsal heads (Eisenhardt et al, 1996; Snow et al, 1992; Yung-Hui and Wei-Hsien, 2005) and raises the peak pressure in the forefoot (Mandato and Nester, 1999; Snow et al, 1992). In this study, the peak plantar pressure under the hallux, 1st, and 2nd MTH was increased, and decreased under the 5th MTH and heel according to the height of heel lifts in the obese group and non-obese group. These results are consistent with those of Yung-Hui and Wei-Hsien (2005) that investigated the change of foot pressure distribution according to increasing heel height (flat shoe, low heel, and high heel). They reported that increasing heel height shifted pressure form the heel and mid foot areas to the forefoot area. Previous

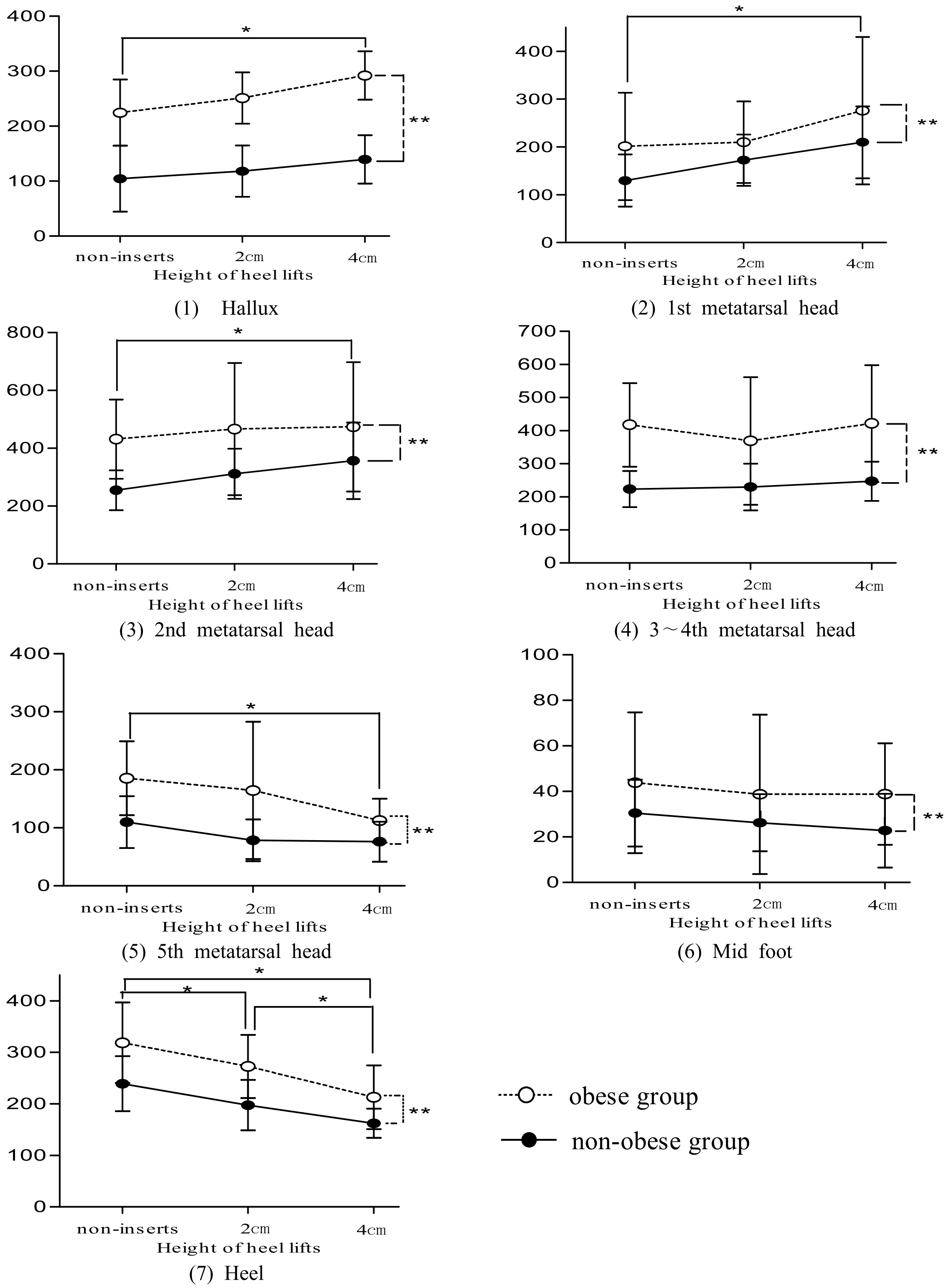

Figure 3. Comparison of the two-factor mixed factorial ANOVA of peak plantar pressure between obese and non-obese group. *Post-hoc analysis by Bonferroni's adjustment p<.017. **Significantly different between group of obese and non-obese (p<.05).

study indicated that women wearing higher heels would have the higher arch type (McCrory et al, 1997). The higher arch may cause lower peak pressure in the mid foot, and increase pressure in medial forefoot (Morag and Cavanagh, 1999). The pressure of the heel region was also shifted to the forefoot region (Mandato and Nester, 1999). Morg and Cavanagh (1999) suggested that the alterations of these pressures may lead to the discomfort of the foot and may cause plantar fasciitis. When wearing high heels, the shock absorption in pronation may be lost because of increased plantar flexion of the ankle joint and supination of the subtalar joint in th initial stance phase (Snow and Williams, 1994). A loss of the ability to weaken the shock waves may increase risk of low back pain and degenerative joint disorders (Yung-Hui and Wei-Hsien, 2005). The results according to the height of heel lifts in shoes showed similar patterns of plantar pressure to high-heeled shoes. We proposed that the heel lifts in shoe must be used cautiously, because the use of heel lifts may be encouraged patients with limited dorsiflexion but, there are the same risk of wearing high-heeled shoes.

Plantar pressure measurements can be used to evaluate potential risk factors for diabetic foot ulceration, and to design footwear, to evaluate the effect of foot orthoses, and to determine plantar pressure at the foot (Martínez-Nova et al, 2008). Martínez-Nova et al (2008) proposed that peak plantar pressure was slightly less reliable in all regions of the forefoot than mean pressure because of the variability associated with gait. Nevertheless, this study measured the peak plantar pressure because it represents the highest value during walking.

The limitation of this study was a small number of subjects in both groups. We assessed only the peak plantar pressure in this study and did not assess total plantar force, total contact area, percentage of body weight, and duration of stance phase, which are important to precisely analyze foot pressure. Further studies are needed to investigate methods to modify the high plantar pressure on the forefoot such as a heel cup, arch supports, a metatarsal pad, and a total contact insert to wear inside shoes with heel lifts.

Conclusion

This study assessed the peak plantar pressure distribution under the hallux, 1st MTH, 2nd MTH, 3~4th MTH, 5th MTH, mid foot, and heel according to the height of heel lifts (non-insert, 2 ㎝ heel lifts, and 4 ㎝ heel lifts) in obese adults and non-obese adults during walking. The obese group had significantly higher peak plantar pressure under all foot areas than the non-obese group regardless of the height of heel lifts. The peak plantar pressure under the 5th MTH and heel was decreased, and peak plantar pressure under forefoot was increased according to the height of heel lifts in the obese group and non-obese group. We proposed that individuals with heel lifts in shoes should be careful, as there is high plantar pressure under the forefoot.

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