



Original Article

## Comparison of Foot Structure, Function, Plantar Pressure and Balance Ability According to the Body Mass Index of Young Adults



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### ABSTRACT

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**Objectives:** This study compared foot arch height, plantar fascia thickness, a range of motion assessments of the ankle joint, strength of the ankle joint, plantar pressure, and balance between obese and normal weight young adults.

**Methods:** Fifty-two participants were required for the present study design to achieve 80% power, 0.8 effect size ( $\eta^2$ ), and an alpha level of 0.05. The participants were categorized to normal weight or obese groups based on BMI ( $\leq 24 \text{ kg/m}^2$  and  $\geq 25 \text{ kg/m}^2$ , respectively). The foot and ankle disability index and Sport survey were completed by the participants before the measurements. Foot arch height was measured using the navicular drop test, and plantar fascia thickness was measured using ultrasound. Plantar pressure and balance tests were also conducted, followed by ankle joint range of motion and strength tests.

**Results:** Foot arch height and plantar fascia thickness was significantly higher in the obese group compared with the normal weight group ( $p < 0.01$ ). There were significant differences in eversion of ankle strength, plantar pressure in the big toe and heel and anterior-posterior balance between normal and obese weight groups ( $p < 0.05$ ).

**Conclusion:** Obese young adults had more abnormalities in the medial longitudinal arch, plantar fascia, and plantar pressure as well as weakened ankle eversion strength and balance problems compared with the normal weight group.

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## Introduction

Obesity is a serious public health issue that has been gradually increasing in all age ranges. The World Health Organization has recognized its severity, and has declared that obesity is an epidemic of the 21st century [1]. Obesity is a severe disease which adversely impacts mortality by increasing the risk of chronic diseases such as cardiovascular disease, hypertension, and diabetes [2,3]. Furthermore, obesity lowers the quality of life, and can negatively affect psychosocial

mental health [4]. Medical problems related to obesity carry a heavy financial cost which has major impacts on national budgets.

In the USA and the United Kingdom, obese individuals have 30% more spent on medical costs than individuals of normal weight [5]. In previous studies in the middle aged and elderly in USA, it was shown that obese individuals had a larger socioeconomic cost than normal weight individuals and the cost increases even more in morbidly obese cases [6,7]. In Korea, the obesity rate is trending similarly, and the National

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Health Insurance Service has announced that medical costs related to obesity increased by 40.49% from 2007 to 2011 [8]. Recent studies have shown that individuals with a body mass index (BMI) of  $25 \text{ kg/m}^2$  or higher, had a significantly higher probability of using medical services than individuals with a normal BMI, and their medical costs also increased 10% in 2011 to 2012 [9].

In Korea, changes in diets and living environments have caused obesity to steadily increase, resulting in a corresponding impact on escalating medical costs. There is currently no systematic countermeasure for this increase in obesity, indicating that the government needs to implement an obesity prevention and management program at a national level [9]. Previous studies on obesity have focused on corrective restrictions on daily life activities caused by osteoporosis, weight loss, surgery, lumbago, ambulatory disabilities, and weakened lower limbs [10,11]. However, no studies have analyzed foot structure and its changes in function in obese individuals.

The feet are constantly exposed to weight-bearing strains in obese individuals. During normal gait, the weight in the feet is approximately 1.2 times the body weight and increases to 2-3 times the body weight when running [12,13]. In obese individuals, weight bearing on the medial longitudinal arch is approximately 3 times greater than it is in normal weight individuals [14], which can cause negative biodynamic changes that may potentially decrease the quality of life, and restrict physical activity [10,15]. Furthermore, decreased physical activity can lead to weakened muscle strength due to restricted motion [16].

Excessive weight-bearing on feet due to obesity causes abnormal structural and functional changes in the foot. Furthermore, it results in decreased physical activity and weakened muscles, and leads to a series of unfortunate symptoms. These complications may increase socioeconomic costs related to obesity, and hence, preventing obesity is important. Recent studies on flat feet showed the importance of investigating the pathophysiology of plantar fasciitis and abnormalities of the feet in obese female adults [17]. In this study, the foot arch height, plantar fascia thickness, range of motion of the ankle joint, strength of the ankle joint, plantar pressure, and balance were analyzed to compare obese and normal weight young adults.

## Materials and Methods

### 1. Participants

There were 52 adults in their 20s who participated in this study: 26 with a BMI of  $\leq 24 \text{ kg/m}^2$  and 26 with a BMI of

$\geq 25 \text{ kg/m}^2$ . In Korea, the standard of obesity is BMI of  $\geq 25 \text{ kg/m}^2$ . The participant pool was analyzed using G-Power analysis, and the effect size, power, and significance were set at 0.8, 0.8, and  $\alpha = 0.05$ , respectively. Classification of normal weight and obesity was performed according to Asian BMI [18]. To accurately measure the participants' BMI, an impedance body composition analyzer (Inbody 230, Inbody Inc., Korea) was used. The study procedure was fully explained to those who agreed to participate in the study. Participants with a history of foot diseases or surgical history, and those who were currently undergoing obesity-related interventions were excluded. This study was approved by the Kaya University Institutional Review Board (approval no.: 20180203) and was undertaken with the consent of the individuals in this study.

### 2. Measurements

#### 2.1. Measurement of foot arch height

To measure foot arch height, a functional navicular drop test was performed. With the participant sitting on a chair and their feet placed on the floor (without bearing weight), the distance between the floor and the navicular tuberosity was measured. The distance between the floor and the navicular tuberosity was then measured while the participant was standing, weight bearing on both feet. The 2 measurements were compared and a difference of 10 mm or more indicated flat feet [19].

#### 2.2. Plantar fascia thickness test

An ultrasound device (Prosound 2, Hitachi Aloka Medical, Japan) was used to measure the thickness of the plantar fascia. A 6-13 MHz linear probe was used and the measurement was taken while the participant was in a prone position with the ankle joint at a  $90^\circ$  angle. The probe was placed vertically on the medial aspect of the calcaneal tuberosity, and the plantar fascia thickness was measured [20].

#### 2.3. Plantar pressure and balance tests

A Tekscan pressure mapping tool (Tekscan pressure mapping tool, Tekscan Inc., USA) was used to determine the distribution of plantar pressure and the changes in the center of mass. Plantar pressure was measured for 5 seconds while the participant was comfortably standing on the pressure mapping tool. The measurements were recorded by video. The image of the foot was divided into 3 identical cells: big toe, little toe, and heel. Excluding the first second and the last second, the mean values of the measurements recorded in the middle 3 seconds were used (Figure 1). Balance was assessed by having the participants stand on the pressure mapping tool on their dominant foot for 10 seconds. Excluding the first and the last 2 seconds, the measurements of the middle 6 seconds were used to evaluate changes in the center of pressure.



Figure 1. Schematic illustration of foot pressure areas determined by the pressure mapping tool.

#### 2.4. Ankle joint range of motion and strength tests

The participants were asked to maintain a supine position with the ankle joint in a neutral position. The degree of dorsiflexion on the ankle joints was measured and the degree of their plantar flexion was measured in the same position [21]. Ankle joint strength was evaluated through dorsiflexion, plantar flexion, inversion, and eversion. The ankle joint strength test was conducted using the guidelines provided by Hislop et al [22] and a Commander muscle tester (Commander muscle tester, JTECH Medical Inc., USA) was used for the measurements.

#### 2.5. Foot and ankle disability index (FADI)

The FADI is composed of 26 categories related to daily activities. Each category is scored from 0 to 4 points. The FADI sports evaluation can also be used to evaluate foot and ankle disability. FADI-Sport is composed of 8 categories related to sports activities with a score range also from 0 to 4 points. The measurement confidence levels of FADI and FADI-Sport are outstanding at 0.89 and 0.84, respectively [23].

### 3. Procedure

In this study, the participants were divided into normal weight and obese groups based on a BMI of  $\leq 24 \text{ kg/m}^2$  and  $\geq 25 \text{ kg/m}^2$ , respectively, to analyze body composition. FADI and FADI-Sport surveys were completed by the participants before the measurements. All feet evaluations were measured on the dominant foot of each participant. Foot arch height was measured using the navicular drop test and plantar fascia thickness was measured using ultrasound. Plantar pressure and balance tests were conducted afterward followed by ankle joint range of motion and strength tests.

### 4. Statistical analysis

The collected data were analyzed using SPSS version 18.0 for Windows (SPSS Inc., Chicago, IL, USA), and the participants' general characteristics were analyzed using descriptive statistics. The difference between normal weight and obese groups were analyzed using an independent t test. For ultrasound measurements, the inter-rater and intra-rater reliabilities were analyzed using intraclass correlation coefficient (ICC)<sub>2,1</sub> and ICC<sub>3,1</sub>. The statistical significance level was set to 0.05.

## Results

All participants' general characteristics are shown in Table 1. The mean age and height in both the normal and obese patients were broadly similar. As expected, the mean weight and BMI in the obese group ( $83.31 \pm 19.35 \text{ kg}$  and  $29.11 \pm 3.98 \text{ kg/m}^2$ , respectively) was markedly higher than in the normal group ( $58.13 \pm 8.56 \text{ kg}$  and  $21.11 \pm 2.06 \text{ kg/m}^2$ , respectively).

Measurement of physical differences in foot structure and function showed that in obese participants, significantly higher values were obtained for the navicular drop test (NDT) and plantar fascia thickness (PFT) than in normal weight participants ( $p = 0.001$ ; Table 2). Obese participants were also shown to have significantly lower ankle eversion strength (AES) test values compared with normal weight participants ( $p = 0.003$ ; Table 2). No other significant differences in foot

Table 1. General characteristics of participants ( $n = 52$ ).

Weight group	Age (y)	Height (cm)	Weight (kg)	BMI (kg/m <sup>2</sup> )	Gender
Normal	23.65 ± 1.55	165.65 ± 8.02	58.13 ± 8.56	21.11 ± 2.06	M (9), F (17)
Obese	24.50 ± 2.30	169.96 ± 9.04	83.31 ± 19.35	29.11 ± 3.98	M (12), F (14)

BMI = body mass index; F = female; M = male.

Table 2. Comparison of foot structure, and function between the normal and obese weight groups ( $n = 52$ ).

	Normal weight group	Obese weight group	t	p
NDT (mm)	4.19 ± 3.31	9.23 ± 3.24	-5.55	0.001
PFT (cm)	0.32 ± 0.04	0.42 ± 0.06	-7.26	0.001
ADF (°)	28.08 ± 8.50	27.50 ± 9.82	0.23	0.822
APF (°)	55.00 ± 12.08	56.54 ± 12.57	-0.44	0.659
ADFS (N/kg)	1.82 ± 0.40	1.88 ± 0.59	-0.47	0.641
APFS (N/kg)	1.90 ± 0.30	2.04 ± 0.43	-1.37	0.177
AES (N/kg)	1.07 ± 0.17	0.91 ± 0.20	3.13	0.003
AIS (N/kg)	0.90 ± 0.21	0.95 ± 0.20	-0.75	0.458
FADI (%)	95.35 ± 7.99	94.58 ± 8.42	0.34	0.736
FADI-Sport (%)	93.63 ± 12.23	91.71 ± 11.55	0.58	0.563

ADF = ankle dorsi-flexion; ADFS = ankle dorsi-flexion strength; AES = ankle eversion strength; AIS = ankle inversion strength; APF = ankle plantar-flexion; APFS = ankle plantar-flexion strength; FADI = foot and ankle disability index; NDT = navicular drop test; PFT = plantar fascia thickness.

Table 3. Comparison of foot pressure and balance between normal and obese weight groups ( $n = 52$ ).

	Normal weight group	Obese weight group	t	p
FPBFS (mmHg/cm <sup>2</sup> )	523.38 ± 178.25	704.54 ± 217.01	-3.29	0.002
FPBFF (mmHg/cm <sup>2</sup> )	491.46 ± 157.35	571.73 ± 184.54	-1.69	0.098
FPH (mmHg/cm <sup>2</sup> )	736.58 ± 185.13	992.42 ± 216.56	-4.58	0.001
OLS-APS (cm)	1.56 ± 0.35	1.88 ± 0.60	-2.30	0.025
OLS-LRS (cm)	2.13 ± 0.70	2.52 ± 1.13	-1.51	0.138

FPH = foot pressure in heel; FPBFF = foot pressure between 4<sup>th</sup> & 5<sup>th</sup> metatarsal bone; FPBFS = foot pressure between first & second metatarsal bone; OLS-APS = one leg stand-anterior and posterior sway; OLS-LRS = one leg stand-left and right sway.

Table 4. Intra and inter-rater reliability of measurements of plantar fascia ( $n = 10$ ).

	Inter-rater		Intra-rater	
	ICC <sub>2,1</sub>	95% CI	ICC <sub>3,1</sub>	95% CI
Plantar fascia	0.894	0.727 - 0.970	0.947	0.855 - 0.985

ICC = intra-class correlation coefficients; CI = confidence interval.

structure and function tests were observed between obese and normal weight participants were observed (Table 2).

When participants were assessed for the distribution of pressure along their feet using a pressure mapping tool, it was shown that significantly higher measurements were observed for foot pressure between the 1<sup>st</sup> and 2<sup>nd</sup> metatarsal bone, foot pressure in heel, and “one leg stand-anterior and posterior sway,” in obese participants compared with normal weight

participants ( $p < 0.05$ ; Table 3). In contrast, no significant differences were observed in foot pressure between the 4<sup>th</sup> and 5<sup>th</sup> metatarsal bone, and the “one leg stand-left and right sway” measurements.

Ultrasound measurements of plantar fascia thickness showed inter- and intra-rater reliability of 0.89 and 0.94, respectively (Table 4).

## Discussion

In this study, structural and functional changes on young adults' feet as well as changes in balance secondary to obesity were analyzed in order to develop an intervention that could prevent these changes. Foot arch height, plantar fascia thickness, ankle joint range of motion, ankle joint strength, distribution of plantar pressure, and balance on one foot were investigated and compared between normal weight and obese groups.

The obese group showed a significantly higher foot arch height than the normal weight group (as determined by NDT). The mean foot arch height change in the obese group was 9.23 mm, which was close to the flat foot diagnostic threshold of 10 mm. This result indicates problems with the medial longitudinal arch and is consistent with the results of previous studies showing structural and functional abnormalities of the medial longitudinal arch in obese patients [24-26]. The plantar fascia is the structure that maintains the shape of the medial longitudinal arch and provides mechanical support to the foot [27]. The obese group in this study had a relatively greater thickness of the plantar fascia, which is inferred to be secondary to the increased activity of the plantar fascia due to increased weight bearing and support.

Obesity is a risk factor for plantar fasciitis [15,28], and a mean plantar fascia thickness of 4.8 mm has been reported in patients with plantar fasciitis [29]. However, the mean plantar fascia thickness of obese patients in this study was 4.2 mm, which is 0.6 mm less than the mean thickness observed in patients with plantar fasciitis. According to previous studies, mean navicular drop test measurement and plantar fascia thickness in young adults with flat feet were 11.08 mm and 4.7 mm, respectively [17]. Considering the changes in foot arch height and plantar fascia thickness in the obese group in this study, obese patients' feet could eventually develop into flat feet and plantar fasciitis without appropriate weight loss and intervention programs, even if obese young adults do not currently have structural or functional problems in their feet.

Obese and overweight patients have a higher mean plantar pressure than normal weight individuals [14,26]. Previous studies have reported increased plantar pressure on the heel and second and fourth metatarsal bones in male participants with a BMI of  $\geq 25$  kg/m<sup>2</sup> [14]. In this study, the obese group had a higher plantar pressure on the first metatarsal bone, second metatarsal bone, and heel than the normal weight group. This observation is thought to be due to the decreased medial longitudinal arch and increased weight bearing on the plantar fascia. Pronation of the foot secondary to decreased medial longitudinal arch and excessive weight bearing on the plantar fascia's origin and insertion seem to have caused increased plantar pressure on the 1<sup>st</sup> metatarsal bone, 2<sup>nd</sup>

metatarsal bone, and heel.

The obese group in this study had a greater decrease in medial longitudinal arch height and anterior-posterior balance while standing on one foot. This result coincides with that of a previous study [30] showing that decreased medial longitudinal arch height could affect posterior balance. Furthermore, decreased anterior-posterior balance not only causes a decrease in medial longitudinal arch height but also causes problems in the foot's mechanoreceptors. A study by Handrigan et al [31] reported that increased weight can decrease the quality of proprioceptive information necessary for balance by putting excessive weight above the detection threshold on the foot's mechanoreceptors.

Furthermore, ankle strength, which is related to ankle motion, is a strong predictor of ankle stability and balance [32]. The eversion strength of the ankle is especially important for preventing ankle sprain [33]. In this study, a significant decrease in eversion strength of the ankle joint was observed in the obese group relative to the normal weight group, which indicates a higher probability of ankle sprain. Although FADI and FADI-Sport scores did not significantly differ in this study, the probability of acute or chronic activity restrictions is very high in patients whose BMI is higher than 25 kg/m<sup>2</sup> [34]. Hence, obese young adults should undergo periodic evaluations of foot structure and function. Further studies are needed to develop management programs to improve structural and functional problems in the feet of obese young adults.

The present study had some limitations. There was a lack of detailed classification of obesity and most of the population was selected from participants in their 20s, which may limit conclusions for the general population.

## Conclusion

Obese young adults had more abnormalities in the medial longitudinal arch, plantar fascia, and plantar pressure as well as weakened ankle eversion strength and balance problems compared with the normal weight group. To prevent these abnormal changes, the development of a foot management program and its application are needed.

## Conflicts of Interest

All the authors of this study declare no conflicts of interest.

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