The immediate effects of foot pressure based insole on ankle dorsiflexion range of motion, postural sway, and muscle activation in healthy adults with genu varum

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Objective: The purpose of this research was to determine the immediate effects of wearing a foot-pressure-based insole (FPBI) on ankle dorsiflexion range of motion (DFROM), postural sway, and muscle activation in healthy individuals with genu varum.

Design: Cross-sectional study.

Methods: This study was conducted on thirteen adults, with six male and seven females subjects. The mean age was 24.08 years. Foot pressure was measured to apply the FPBI and the weight bearing lunge test was performed with the application of a flat insole (FI) and FPBI. Examination was randomly performed in four conditions to measure both postural sway and muscle activation. All participants applied both the FI and FPBI with four conditions. The four conditions were as follows: 1) Romberg test posture with eyes closed, 2) Romberg test posture with eyes opened, 3) dominant single leg standing with eyes opened, and 4) non-dominant single leg standing with eyes opened.

Results: For ankle DFROM between the FI and FPBI, a significant increase was observed in both the dominant and non-dominant leg ($p < 0.05$). For postural sway between the FI and FPBI in the Romberg test posture with eyes closed and dominant single leg standing with eyes opened conditions, a significant decrease was observed ($p < 0.05$). However, the postural sway between FI and FPBI in the Romberg test posture with eyes opened and non-dominant single leg standing with eyes opened, no significant decrease was observed. Also, there were no significant effects on muscle activation between the application of the FI and FPBI.

Conclusions: The result showed that FPBI immediately improved ankle DFROM and postural sway. It seems that FPBI may improve genu varum in healthy individuals with genu varum.

Key Words: Ankle dorsiflexion range of motion, Genu varum, Orthotic devices, Postural balance

Introduction

Genu valgum and genu varum are commonly reported as knee joint deformities [1]. Genu varum has been previously shown to increase the risk of osteoarthritis [2] and genu varum is common in osteoarthritis, because knee osteoarthritis more often affects the medial than the lateral compartment [3]. In bilateral standing with normal knee alignment, the weight-bearing line of the lower extremity passes through the center of the knee joint, thus the weight is distributed to

the middle of the knee joint [4,5]. But in genu varum, the weight-bearing line is shifted from the middle to the medial part of the knee joint and the compressive forces over the medial part of the knee joint is increased [6].

A lateral wedge insole has been commonly used for genu varum for osteoarthritis [7-9] because it reduce pain [10] and knee adduction moment [11]. It also improves functions involved in physical activity, such as walking distance [7] and static balance [12]. It is also low-cost, and low-burden on self-management for managing genu varum with osteo-

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arthritis [13].

Generally, genu varum caused by supination of hindfoot and pronation of forefoot and midfoot affects the quality of postural control [14], and poor postural control was reported in supinated or pronated feet during single-leg stance [15]. This may change the ground reaction force within the frontal plane and change the center of pressure location on the plantar side of the foot [6], which may disturb the balance control strategy during physical activity [16]. Increased subtalar pronation or supination moment may change the gravitation torque force on the foot and create stress over the longitudinal arch of the foot and thus postural stability may be affected by foot type in both static and dynamic conditions [14]. Another study also suggested that foot posture may have an influence on dynamic and static postural control with eye closed in those with chronic ankle instability [17]. Therefore, genu varum may have an influence on ankle instability.

Ankle dorsiflexion range of motion (DFROM) is often a point of emphasis during the rehabilitation of lower extremity pathologies [18]. In subjects with chronic ankle instability, foot pressure may influence several of the postural and DFROM measurements [14,15,19]. Ankle DFROM influences dynamic balance in subjects with chronic ankle instability [20]. Also, Ankle DFROM can play an important role in determining ankle dorsiflexor strength in young adults [21]. Another study reported that plantar flexor muscle strength was related to postural stability in healthy subjects [22].

Genu varum is related to external rotation of the hip joint, as well as posterior pelvic tilt, rearfoot supination, and elevation of the medial longitudinal arch [23]. Therefore, this posture affects muscle activation and strength in the lower extremities. A previous study showed that the genu varum group had more muscle activity in the vastus medialis than in the vastus lateralis and rectus femoris [24]. The vastus medialis/vastus lateralis ratio was also significantly higher in with genu varum than in values for both genu valgum and normal knee alignment [25].

Previous studies only reported the effects of applying a lateral wedge for genu varum with ankle DFROM [26], postural sway [12], or muscle activation [24]. However, there are no studies that investigated the combination of ankle DFROM, postural sway, and muscle activation. Therefore, this study was designed to investigate the immediate effects of wearing a foot-pressure-based insole (FPBI) on ankle DFROM, postural sway, and muscle activation in healthy in-

dividuals with genu varum.

Methods

Participants

Thirteen subjects who had genu varum from Sahmyook University (Seoul, Korea) participated in this study. The inclusion criteria for this study were those with genu varum (gap in the medial epicondyle of the knee ≥ 3 cm) and age between 20 to 29 years. Subjects with ankle sprain within 3 months, history of neuro-musculo-skeletal diseases, history of trauma or fracture in the lower limbs during the last year, professional athletes, and other lower limb deformities were excluded from the study [16].

The present study was approved by the Sahmyook University Institutional Review Board (IRB No. 2-1040781-AB-N-01-2017023HR). The objectives of the study and its requirements were explained to the subjects, and all participants provided written consent in accordance with the ethical principles of the Declaration of Helsinki.

Procedures

One hundred forty-two subjects from freshman to junior year who study at the Sahmyook University (Seoul, Korea) Physical Therapy department were recruited. There were twenty-seven subjects with genu varum. There were twenty-seven subjects with genu varum but those who had an ankle sprain within 3 months had to be excluded, leaving a total of thirteen subjects. They were examined based on the inclusion and exclusion criteria, and informed consent regard to the examination procedure and duration was obtained.

Foot pressure was measured to apply the FPBI. The weight-bearing lunge test (WBLT) was performed with application of a flat insole (FI) and FPBI that was the same shape as the shoes. Measurement of postural sway and muscle activation were randomly performed in the Romberg test posture with eyes opened, Romberg test posture with eyes closed, dominant single leg standing with eyes opened, and non-dominant single leg standing with eyes opened conditions with the same shape as the shoes. All participants had the application of both FI and FPBI for all four conditions.

Experimental methods

Measurement of genu varum

In this study, genu varum was measured to select participants. To evaluate the genu varum, the participants were asked to stand against the wall with their back, buttocks

and both heels touching the wall. They were required to stand in an anatomical position bare-footed. Then the subjects were asked to put their feet together. A gap of more than 3 cm between the two medial knee epicondyles was considered as genu varum [16,27].

Measurement of foot pressure

In this study, foot pressure was measured with the Zebris platform (Zebris FDM 1.5, 2016; ZEBRIS Medical, Isny, Germany). Measurement was done in an anatomical position, facing the front, and feet pelvic-width apart, bare-footed. Foot pressure was measured three times to minimize error of measurement.

Application of the FPBI

Based on the foot pressure, a 3 or 8-mm lateral wedge, which was made of silicon, were selectively applied to all participants (Figure 1). For those with a high arch, we ap-

Figure 1. Foot pressure based insole.

plied an 8-mm lateral wedge. For those with a normal arch, the 3 mm lateral wedge was applied. FI with non-wedged 1 mm thick, which was made of sponge, covered the whole shoe. It also covered the FPBI.

Measurement of ankle DFROM

In this study, ankle DFROM was measured with the WBLT [28,29]. The WBLT was matched between the second toe and center of the heel attached to the floor, and maintain the knee in vertical position on the wall. Distance between the second toe and the wall was recorded to measure ankle dorsiflexion angle indirectly [28]. The WBLT has a high reliability with a high intra-clinician reliability (ICC=0.65-0.99) and inter-clinician reliability (ICC=0.80-0.99) [18]. In this study, the inspector and assistant performed the measurements with both FI and FPBI application, and the average from three repeated measures was used to minimize error of measurement.

Measurement of postural sway

In this study, postural sway was measured with the Zebris platform (FDM 1.5; ZEBRIS Medical). Measurements were done with four positions in two conditions (Figure 2). The four positions were the Romberg test posture with eyes closed, Romberg test posture with eyes opened, dominant single leg standing with eyes open, and non-dominant single leg standing with eyes opened, and the two conditions were the FI and FPBI applications. Postural sway was measured three times for every condition and the average of three repeated measures was used to minimize error of measurement. The measurement was recorded for 20 seconds but data obtained from the middle 10 seconds was used for analysis. Thirty-second rest periods were provided between experi-

Figure 2. Measurement of postural sway and muscle activation. (A) Romberg test position with eye closed. (B) Romberg test position with eye opened. (B, C) Dominant single leg standing with eye opened. (D) Non-dominant single leg standing with eye opened.

ments [30].

Measurement of muscle activation

In this study, muscle activation was measured with the BIOS-mini (Biobrain Inc., Daejeon, Korea, 2016). Measurement was done with four positions in two conditions on the vastus lateralis muscle and medialis muscle of the dominant and non-dominant leg (Figure 2). The four positions were the Romberg test posture with eyes closed, Romberg test posture with eyes opened, dominant single leg standing with eyes open, and non-dominant single leg standing with eyes opened. In the dominant single leg standing condition, we measured muscle activation of the dominant leg. The two conditions were the FI and FPBI.

Before examining muscle activation, the electrode attachment site was cleaned with an alcohol swab, followed by removal of body hair to reduce skin resistance. Maximum voluntary isometric contraction (MVIC) was examined to calculate the root mean square (RMS). Muscle activation and MVIC was measured three times in every condition. The measurement was recorded for 20 seconds, and the middle of 10 seconds was used for analysis, and the average obtained from three repeated measures was used to minimize error of measurement.

Measurement tools

Zebri FDM software and platform

The 'ZEBRIS Win FDM' software was used for data collection and analysis where measurements were taken in standing position with the aid of a customary measurement platform (FDM 1.5; ZEBRIS Medical).

In this study, a platform was used to measure foot pressure and static postural sway of healthy individuals with genu varum with double leg standing and single leg standing positions. The platform size was 1,580 mm in length × 605 mm in width × 21 mm in height. It incorporates 11,264 sensors on an area of 64 by 176 cm, giving a resolution of ap-

proximately 4 sensors per square centimeter. All sensors were measured independently, the measuring frequency was 100 Hz, and reported accuracy was within 5%.

Wireless 8-channel surface electromyography

In this study, the BIOS-mini electrocardiogram (EKG), and surface electromyography (sEMG), which was completely wireless with an 8-channel measurement equipment, was used. EMG signal which analog signal was discrete digitizing to 1,000 Hz sampling frequency to possibly calculate index in data processing system, and digital resolving power is 24 bit.

After converting to digital signals, they were wirelessly sent to a personal computer to BioScan (2017; Biobrain Inc.), which is a professional EMG analysis program. Bioscan was applied with a 4-500 Hz Band-Pass Filter. After applying 60, 120, and 180 Hz Notch Filter to remove noise of power supply, the RMS index, which reflect muscle activation, was calculated.

Statistical analysis

All general characteristics of subjects were normally distributed. The PASW Statistics ver. 18.0 software (IBM Co., Armonk, NY, USA) was used for all statistical analysis. Results were presented as mean±standard deviation. Paired t-test was used to compare the results between the FPBI and FI. For all tests, the level of statistical significance was set to 0.05.

Results

General characteristics of subject

Thirteen subjects participated in this study. Demographic characteristics were shown in Table 1.

Table 1. General characteristics of subject (N=13)

Characteristic	Experimental group
Gender (male/female)	13 (6/7)
Age (y)	24.08 (3.01)
Height (cm)	167.82 (9.73)
Weight (kg)	58.42 (9.96)
Body mass index (kg/m ²)	20.64 (2.30)

Values are presented as number only or mean (SD).

Table 2. Ankle dorsiflexion range of motion (N=13)

Side	FPBI	FI	t (p)
Dominant leg (cm)	14.73 (2.93)	12.62 (3.04)	5.628 (<0.001)*
Non-dominant leg (cm)	14.27 (3.61)	13.05 (2.92)	3.666 (0.003)*

Values are presented as mean (SD).

FPBI: foot pressure based insole, FI: flat insole.

* $p < 0.05$.

Ankle DFROM

The results of ankle DFROM are shown in Table 2. In ankle DFROM between FI and FPBI, a significant increase was observed in both the dominant and non-dominant leg ($p < 0.05$).

Postural sway

The results of postural sway are shown in Table 3. In the 95% confidence ellipse area, center of pressure (COP) path, and COP average velocity between FI and FPBI in the Romberg posture with eyes closed, a significant decrease was observed ($p < 0.05$). In the 95% confidence ellipse area, COP path, and COP average velocity between FI and FPBI in Romberg posture with eyes opened, no significant decrease was observed ($p > 0.05$). In the 95% confidence ellipse area, the COP path and COP average velocity between FI and FPBI in the dominant single leg standing position with eyes opened, a significant decrease was observed ($p < 0.05$). In the 95% confidence ellipse area, the COP path and COP average velocity between FI and FPBI in the non-dominant single leg standing position with eyes opened, no significant decrease was observed ($p > 0.05$).

Muscle activation

The results of muscle activation are shown in Table 4. In

muscle activation between FI and FPBI in the Romberg position with eyes closed condition, no significant decreases in vastus lateralis and medialis of the dominant leg and vastus lateralis and medialis of the non-dominant leg was observed ($p > 0.05$). In muscle activation between the FI and FPBI in the Romberg position with eyes opened condition, no significant decreases in vastus lateralis and medialis of dominant leg and vastus lateralis of non-dominant leg was observed ($p > 0.05$). In muscle activation between FI and FPBI in the Romberg position with eyes opened condition, no significant increases in vastus medialis of non-dominant leg was observed ($p > 0.05$).

In muscle activation between the FI and FPBI in the dominant single leg standing with eyes opened condition, no significant increases in the vastus lateralis and medialis of the dominant leg was observed ($p > 0.05$). In muscle activation between the FI and FPBI in the non-dominant single leg standing with eyes opened condition, no significant decreases in vastus lateralis and medialis of non-dominant leg was observed ($p > 0.05$).

Discussion

Genu varum increases the risk of osteoarthritis and it affects postural control. Therefore, this study was designed to investigate the effects of FPBI on ankle DFROM, postural

Table 3. Postural sway

(N=13)

Sway	FPBI	FI	t (p)
Romberg with eye closed			
CEA (mm ²)	409.96 (178.22)	625.72 (375.71)	2.756 (0.017)*
CPL (mm)	145.12 (37.01)	169.04 (37.56)	2.714 (0.019)*
CAV (mm/s)	14.54 (3.71)	16.88 (3.80)	2.632 (0.022)*
Romberg with eye opened			
CEA (mm ²)	245.41 (152.30)	316.31 (295.32)	1.414 (0.183)
CPL (mm)	90.00 (25.49)	93.69 (33.24)	0.826 (0.425)
CAV (mm/s)	8.95 (2.55)	9.38 (3.37)	1.019 (0.328)
Dominant single leg standing with eye opened			
CEA (mm ²)	412.18 (166.29)	485.00 (180.64)	2.239 (0.045)*
CPL (mm)	273.17 (85.15)	299.27 (86.51)	2.533 (0.026)*
CAV (mm/s)	27.47 (8.58)	30.00 (8.64)	2.437 (0.031)*
Non-dominant single leg standing with eye opened			
CEA (mm ²)	426.55 (191.25)	486.49 (166.50)	1.708 (0.113)
CPL (mm)	268.03 (53.05)	291.12 (68.57)	1.516 (0.155)
CAV (mm/s)	26.82 (5.21)	29.17 (3.80)	1.529 (0.152)

Values are presented as mean (SD).

FPBI: foot pressure based insole, FI: flat insole, CEA: 95% confidence ellipse area, CPL: COP path length, CAV: COP average velocity.

* $p < 0.05$.

Table 4. Muscle activation (electromyography)

(N=13)

Muscle	FPBI	FI	t (p)
Romberg test posture with eye closed			
Dominant VL (MVIC%)	3.84 (3.76)	5.34 (5.64)	1.897 (0.082)
Dominant VM (MVIC%)	6.34 (8.92)	6.52 (7.99)	0.171 (0.867)
Non-dominant VL (MVIC%)	3.91 (3.64)	6.06 (7.90)	1.631 (0.129)
Non-dominant VM (MVIC%)	8.91 (10.97)	9.34 (14.33)	0.143 (0.888)
Romberg test posture with eye opened			
Dominant VL (MVIC%)	2.36 (1.50)	3.59 (3.52)	1.402 (0.186)
Dominant VM (MVIC%)	5.16 (6.26)	6.28 (10.18)	0.909 (0.381)
Non-dominant VL (MVIC%)	3.06 (3.14)	4.01 (4.56)	2.153 (0.129)
Non-dominant VM (MVIC%)	8.83 (11.96)	7.96 (10.51)	-1.556 (0.052)
Dominant single leg standing with eye opened			
Dominant VL (MVIC%)	9.39 (10.65)	8.51 (6.95)	-0.430 (0.675)
Dominant VM (MVIC%)	12.42 (12.55)	10.77 (9.92)	-0.019 (0.398)
Non-dominant single leg standing with eye opened			
Non-dominant VL (MVIC%)	11.99 (17.26)	13.72 (21.06)	1.297 (0.219)
Non-dominant VM (MVIC%)	19.31 (26.61)	20.03 (25.49)	0.166 (0.871)

Values are presented as mean (SD).

FPBI: foot pressure based insole, FI: flat insole, VL: vastus lateralis, VM: vastus medialis, MVIC: maximum voluntary isometric contraction.

sway, and muscle activation in healthy adults with genu varum.

In this study, a significant increase in ankle DFROM between FI and FPBI was observed in both the dominant and non-dominant leg ($p < 0.05$). Previous studies reported that lateral wedged insoles produced small changes in ankle dorsiflexion in obese and healthy women [26], and there was a moderate correlation between ankle DFROM and dorsiflexor strength in healthy young adults [21]. It seems that FPBI may release the fascia around the ankle and foot, therefore, decrease the tension around the ankle and foot. Therefore, as the ankle DFROM increases, it is thought that flexibility of the muscle and fascia of the ankle and ankle dorsiflexor strength may have increased due to FPBI. As a result, FPBI may increase ankle DFROM.

Postural balance control was quantified by COP variables, which were velocity moment, total sway area, total sway length and confidence ellipse area [31]. In this study, the 95% confidence ellipse area between the FI and FPBI in the Romberg posture with eyes closed and dominant single leg standing position with eyes opened conditions was significantly decreased ($p < 0.05$). A previous study reported that the medio-lateral range of COP movement and the 95% confidence circle area of sway was significantly reduced after applying prefabricated orthotic insoles [32]. In this study, the COP path length between FI and FPBI in the Romberg posture with eyes closed and dominant single leg standing

position with eyes opened was significantly decreased ($p < 0.05$). A previous study reported that examination during the eyes-closed task demonstrated an immediate reduction in the COP path length after insertion of the textured insoles compared to casual shoes alone in people with multiple sclerosis [33]. In this study, COP average velocity between FI and FPBI in the Romberg posture with eyes closed and dominant single leg standing position with eyes opened was significantly decreased ($p < 0.05$). Previous studies reported individuals in the supinated feet group of healthy young adults had significantly greater COP average speed [15], and mean values of COP total velocity during standing with and without insole were significantly decreased in subjects with flat feet [34]. Postural sway is affected by the visual, proprioception, and vestibular system. When healthy subjects stand on a firm surface, they rely on the visual system 10% for postural orientation [35]. Therefore, it is thought that the Romberg test posture with eyes opened condition might not be significant in this study. In this study, application time with FPBI was twenty minutes. Therefore, it is probably not affected to the non-dominant side of the leg. The main effects of lateral wedges were reductions of external knee adduction moment and of the knee adduction angular impulse [3,36], and the lateral wedge insole shifted the weight bearing line from medial to the middle of the knee joint [6]. Therefore, this structural change may affect changes of muscle activation around the thigh muscle, and pelvic stability

might be increased by co-contraction of the hamstring and quadriceps muscles. Lateral wedge insole may change the location of the navicular bone. Therefore, it may affect the elongation force of the tibialis posterior muscle. Also, a lateral wedge insole assists the ankle to change from supination to neutral position. Thus, sensory input may increase because contact area of the foot on the ground would be increased. Therefore, sensory input area may change from the lateral to the whole part of the foot. Consequently, it seems that FPBI may affect the 95% confidence ellipse area, COP path length, and COP average velocity. As a result, it is thought that FPBI affects postural sway in healthy subjects with genu varum.

In this study, for muscle activation between FI and FPBI in all conditions, no significant difference in all muscles of both dominant and non-dominant leg was observed. Previous studies reported that no statistical differences were observed in the vastus medialis and vastus lateralis for the EMG profiles between wedged and non-wedged conditions found in varum gonarthrosis [37], and standing on a wedge did not affect muscle activity of the proximal part [38]. Overall, the result of our study could support the findings from previous studies. It is considered that no significant effects appeared since this study only showed the immediate effects of applying FPBI. However, increased muscle tension can subsequently improve muscle strength, which can be expected to increase ankle stability [21].

The limitation of this study was as follows. First, we could not assess the long-term changes after applying FPBI because we only observed the immediate effects. Second, the number of subjects was small. Therefore, it is difficult for our results to be generalized to all healthy adults with genu varum. In future research studies, it would be necessary to address these limitations.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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