Foot pain during walking has been associated with increased plantar pressure, and abnormally higher plantar pressure is considered one of direct etiologies of foot pain. As such, many types of insoles are invented to reduce the loading of structures in the lower extremities and are commonly used in the conservative management of foot disorders. The insoles generally aim to change the motion patterns of the lower extremities while walking, readjust the skeletal structure, and provide shock relief and plantar pressure changes, eventually relieving symptoms. In particular, plantar pads or insole prescriptions are used to reduce plantar pressure by redistributing the pressure on the sole of the foot overall. There were several previous reports on how the insoles affect foot and ankle diseases by analyzing plantar pressure. However, the influence of each type of insole on plantar pressure has not been sufficiently studied and there are few data to compare plantar pressure changes between barefoot and

Background: In clinical fields, many types of insoles are used to not only realign movement patterns, but also treat pressure-related foot diseases. However, the characteristics of and plantar pressure in each type of insole are still unclear. Therefore, the aim of this study was to validate the plantar pressure-relieving effect of three representative types of insoles (metatarsal padding insole [MPI], lateral heel wedge insole [LHI], and arch support insole [ASI]) in asymptomatic men.

Methods: A total of 35 feet of 35 asymptomatic men with a mean age of 23.4 ± 2.0 years were included. Pedobarographic data were evaluated by dividing the foot into eight designated regions to compare the three types of insoles. Peak plantar pressure (PPP) and pressure time integral (PTI) were assessed using the Pedar-X system. A repeated measures analysis of variance was used for statistical analyses.

Results: In the hallux region, there was no statistically significant difference. MPI showed highest pressure in the 2nd–5th toe and midfoot region, but lowest in the central and lateral forefoot regions. Meanwhile, ASI showed highest pressure in the medial forefoot region but lowest in the lateral heel region. Lastly, pressure in the lateral heel region was highest in LHI. Overall, results of PTI were similar to those of PPP.

Conclusions: This study demonstrated that the three types of insole each could reduce and redistribute pressure of specific part of the foot to help select an appropriate insole for each purpose.

Keywords: Foot, Pressure, Insole
The product designated for MPI was composed of a convex metatarsal pad, which is just proximal to the metatarsal area. Second, LHI was made of a lateral wedge resulting in 6° of inclination medially in the lateral rearfoot along the full length of the insole, considering comfort and wedge effect. Lastly, ASI designated for the flatfoot consisted of medial arch support application in the midfoot according to the medial arch height as in a previous study. The peak longitudinal height of the midfoot arc in ASI was standardized as 25 mm (Fig. 1). All participants used the same New Balance running shoes. This prefabricated insoles were of full length and made of two layers: ethylenevinyl acetate at the bottom layer and 1-mm-thick polyurethane foam on the top. The material and thickness of the insoles were made to be similar as much as possible (Sam-Hwa Orthosis Service, Seoul, Korea). To reduce sliding between the insoles and the shoes, the insoles were fixed firmly using Velcro. Three sizes of prefabricated insoles (270 mm, 275 mm, and 280 mm) and CI were used for this study.

**Methods**

Prior to study, all participants reviewed the research protocol and signed a consent form and this study was approved by the Institutional Review Board of Seoul National University Hospital (No. H-1711-023-897). At first, 40 young male volunteers were recruited in the study.

Inclusion criteria were as follows: (1) no history of foot and ankle injuries in the past 1 year; (2) no history of lower leg, ankle, and foot surgery or fracture; (3) no observed radiographic features of deformity on simple radiographs of the hip, knee, ankle, or foot; (4) no subjective symptoms such as pain or discomfort during gait. Two male adults with too small feet to fit the shoes and 3 male adults with flat feet (based on radiologic Meary’s angle, talonavicular coverage angle, calcaneal pitch angle, and talocalcaneal angle) were excluded following the protocol. Finally, 35 healthy male adults’ data were analyzed. Demographic data and radiographic variables of the participants are shown in Table 1.

Three types of prefabricated insoles and a control insole (CI) were used in this study. First, a flat insole that completely fitted into the running shoes by a shoe manufacturer (New Balance, Seoul, Korea) was used as a CI. The insole was constructed with foam in the rearfoot, midfoot, and forefoot regions and an inflexible outsole in a running shoe. The product designated for MPI was composed of a convex metatarsal pad, which is just proximal to the metatarsal area with a soft forefoot region and rigid toe insole conditions. In addition, some studies had small experimental groups or reported confusing and nonintuitive results. Traditionally, most plantar pressure measurements have been made with platforms placed between the barefoot and the floor. Recently, pedobarography was introduced to analyze plantar pressure, especially the dynamic pedobarography rather than static. Also, plantar pressure measurements between the foot and the shoe provide a means to better understand the effects of insole design modifications on the mechanics of the foot. Hence, pedobarography is thought to have the potential to influence the research on pressure fields acting between the plantar surface of the foot and a supporting surface. Therefore, the objective of this study was to validate the pressure-relieving effect of prefabricated insoles during gait in asymptomatic men by comparing three types of insoles (metatarsal padding insole [MPI], lateral heel wedge insole [LHI], and arch support insole [ASI]), which can be applied to improve representative foot illnesses related to plantar pressure in clinical fields.

**Experimental Procedures**

The experiment using Pedar-X system took place in a research facility located near a walkway. Data on walking were collected in three separate sessions: practice, trial 1, and trial 2. The practice walk gave them the time to acclimatize before the two trials to obtain quality plantar data. The participants were asked to walk at a speed-controlled and comfortable pace and look ahead for at least 30 steps for all data acquisition processes for the data to be representative of the participants’ plantar data. The CI and the three types of insoles (MPI, LHI, and ASI) were used bilaterally in all participants during data acquisition. All

| Variable          | mean ± SD (range) |
|-------------------|-------------------|
| Age (yr)          | 23.4 ± 2.0 (20 to 28) |
| Shoe size (cm)    | 27 ± 0.6 (26 to 28.5) |
| Height (cm)       | 175.4 ± 4.3 (165 to 186) |
| Weight (kg)       | 73.1 ± 8.2 (49 to 95) |
| BMI (kg/m²)       | 23.7 ± 2.6 (16.4 to 29.4) |
| TNCA (°)          | 13.09 ± 6.2 (24.9 to 1.0) |
| CPA (°)           | 21.42 ± 5.2 (37.8 to 12.5) |
| TCA (°)           | 47.54 ± 4.8 (58.8 to 38.6) |
| Meary’s angle (°) | 1.20 ± 5.4 (13.8 to −10.6) |

SD: standard deviation, BMI: body mass index, TNCA: talonavicular coverage angle, CPA: calcaneal pitch angle, TCA: talocalcaneal angle.
calibrations were done following each platform’s manual guidelines.

Data Analysis
The pedobarographic measurements were estimated by utilizing the Pedar-X in-shoe PP measurement system (Novel, Munich, Germany), composed of a sensor insole and a data analyzer. Sensor insoles were available in European shoe sizes 22–49, 3 types of width, 1.9 mm in thickness, and 99 sensors embedded with a pressure range of 30–1,200 kPa. The data analyzer was 15 × 10 × 4 cm in size and weighed 400 g, which was worn by using a bandage at the waist level. The foot pressures were recorded at a rate of 50 Hz. All analyses were performed on the right foot by selecting 5 representative steps. While, Bergstra et al.15) divided the forefoot quadrants into 2-3-2, we used a modified version of 2-3-3 as defined in software. Those 8 regions were hallux, 2nd–5th toes, medial forefoot (mFF), central forefoot (cFF), lateral forefoot (lFF), midfoot (mid), medial heel (mH), and lateral heel (lH) (Fig. 2). The heel comprised of the first 0% to 30% of the foot length, the midfoot the next 30% to 60%, the forefoot the following 60% to 85%, and the hallux/toe the remaining 85% to 100%.16) Recorded data included peak plantar pressure (PPP) and pressure time integral (PTI). PPP was defined as pressure = force/area, where force means the vertical ground reaction force (GRF) exerted upwards from the ground through the foot and area means the surface area of the foot that is in contact with the ground during walking. The magnitude of stress was characterized as PPP during barefoot walking and walking in shoes. Time factors were characterized as PTI, the duration of pressure application.

Statistical Analysis
Data were evaluated for completeness and normality using the Kolmogorov-Smirnov test and Shapiro-Wilk test combined with normal distribution plots. Analysis of differences among the three types of insoles was performed using a repeated measures analysis of variance. Post hoc analysis was conducted using a Bonferroni test to evaluate pairwise differences in values between the three types of
## Table 2. Descriptive Statistics of PPP (kPa) and PTI (kPa × sec) among Three Different Types of Insoles

| Characteristic | Hallux | 2nd–5th toe | mFF | cFF | lFF | Mid | mH | IH |
|----------------|--------|-------------|-----|-----|-----|-----|----|----|
| **PPP (kPa)** |        |             |     |     |     |     |    |    |
| Mean           |        |             |     |     |     |     |    |    |
| CI             | 261.48 | 135.14      | 195.10 | 182.57 | 112.50 | 110.00 | 213.05 | 211.04 |
| MPI            | 269.42 | 173.31      | 199.97 | 163.02 | 111.85 | 155.18 | 174.11 | 191.40 |
| LHI            | 261.62 | 157.65      | 218.22 | 194.50 | 123.74 | 128.10 | 181.95 | 199.54 |
| ASI            | 267.97 | 164.60      | 225.08 | 190.04 | 118.97 | 142.48 | 181.70 | 188.28 |
| Median         |        |             |     |     |     |     |    |    |
| CI             | 268.50 | 126.00      | 193.00 | 174.50 | 109.50 | 100.00 | 213.00 | 201.50 |
| MPI            | 269.50 | 174.50      | 182.5 | 160.00 | 110.50 | 146.50 | 174.50 | 185.50 |
| LHI            | 256.00 | 156.50      | 213.5 | 183.50 | 121.00 | 120.00 | 181.50 | 192.00 |
| ASI            | 266.50 | 172.50      | 220.00 | 185.50 | 118.00 | 128.00 | 179.00 | 185.00 |
| SD             |        |             |     |     |     |     |    |    |
| CI             | 70.71  | 37.92       | 52.37 | 36.70 | 30.11 | 37.41 | 30.53 | 34.33 |
| MPI            | 66.42  | 31.87       | 62.78 | 31.97 | 25.91 | 42.41 | 28.88 | 31.50 |
| LHI            | 61.56  | 28.70       | 49.79 | 35.59 | 33.99 | 436.89 | 25.77 | 30.02 |
| ASI            | 58.54  | 33.36       | 55.69 | 42.45 | 32.72 | 49.08 | 26.73 | 30.43 |
| **PTI (kPa × sec)** |        |             |     |     |     |     |    |    |
| Mean           |        |             |     |     |     |     |    |    |
| CI             | 48.91  | 29.38       | 44.69 | 45.59 | 36.43 | 40.69 | 47.39 | 49.93 |
| MPI            | 51.40  | 35.81       | 41.78 | 38.85 | 28.80 | 54.92 | 45.66 | 51.04 |
| LHI            | 49.71  | 31.67       | 47.43 | 46.09 | 35.72 | 46.79 | 47.11 | 54.03 |
| ASI            | 51.00  | 32.26       | 46.66 | 43.49 | 32.88 | 52.13 | 46.55 | 48.58 |
| Median         |        |             |     |     |     |     |    |    |
| CI             | 47.60  | 28.96       | 43.93 | 43.82 | 36.33 | 39.58 | 48.10 | 50.50 |
| MPI            | 53.64  | 36.25       | 39.23 | 38.38 | 26.26 | 56.72 | 44.46 | 50.23 |
| LHI            | 47.85  | 31.20       | 47.36 | 45.60 | 36.94 | 45.16 | 47.34 | 54.39 |
| ASI            | 51.60  | 31.58       | 47.23 | 44.09 | 30.26 | 51.69 | 46.35 | 48.50 |
| SD             |        |             |     |     |     |     |    |    |
| CI             | 13.93  | 9.01        | 12.83 | 9.20 | 8.32 | 11.89 | 9.14 | 9.48 |
| MPI            | 15.23  | 6.26        | 12.17 | 7.13 | 10.98 | 9.03 | 8.63 | 9.67 |
| LHI            | 13.42  | 8.24        | 13.62 | 9.91 | 9.76 | 11.27 | 8.39 | 8.68 |
| ASI            | 11.66  | 7.23        | 12.04 | 11.60 | 10.86 | 10.46 | 8.80 | 9.92 |

PPP: peak plantar pressure, PTI: pressure time integral, mFF: medial forefoot, cFF: central forefoot, lFF: lateral forefoot, Mid: midfoot, mH: medial heel, IH: lateral heel, CI: control insole, MPI: metatarsal padding insole, LHI: lateral heel wedge insole, ASI: arch support insole, SD: standard deviation.
insoles in each region. Significance was set at $p < 0.05$. All statistical analyses were performed using the IBM SPSS ver. 24 (IBM Corp., Armonk, NY, USA).

RESULTS

The each and overall pressure patterns of the three different types of insoles are shown in Table 2 and Fig. 3, respectively. There were no statistical differences ($p > 0.05$) in the hallux region among the insole types. However, in the 2nd–5th toe regions, both PPP (mean, 173.31 kPa; standard deviation [SD], 31.87) and PTI (mean, 35.81 kPa × sec; SD, 6.26) in the MPI group were significantly higher than any other groups. In the mFF region, the ASI group showed statistically significantly higher PPP (mean, 225.08 kPa; SD, 55.69) and PTI (mean, 46.66 kPa × sec; SD, 12.04) than the MPI group and CI group. In the cFF region, the MPI group showed statistically significantly lower pressure in both PPP (mean, 163.02 kPa; SD, 31.97) and PTI (mean, 38.85 kPa × sec; SD, 7.13) than the other groups. With regard to PPP, there were no statistically significant differences in the IF region, but PTI was the lowest in the MPI group (mean, 28.80 kPa × sec; SD, 10.98). PTI in the mid region (mean, 54.92 kPa × sec; SD, 9.03) and PPP in the mid region (mean, 155.18 kPa; SD, 42.41) were the highest in the MPI group, followed by ASI, LHI, and CI groups. In the mH region, the CI group showed statistically significantly higher PPP (mean, 213.05 kPa; SD, 30.53) than any other groups. Meanwhile, in the IH region, the LHI group showed statistically significantly highest PPP (mean, 199.54 kPa; SD, 30.02) and PTI (mean, 54.03 kPa × sec; SD, 8.68) except for the CI group (Fig. 4).

DISCUSSION

The three representative types of insoles applied in the study group produced statistically significant differences in terms of pressure shifting and redistribution in the foot sole in asymptomatic men. Previous studies investigating plantar pressure in patients with generalized forefoot pain demonstrated increases in PPP in the forefoot, consistent with PTI. Therefore, MPI prescription, which is composed of padding proximal to the metatarsal head, aims at reducing the pressure in the metatarsal area and redistributing plantar pressures in a balanced manner throughout the foot. A previous study demonstrated that PTI was the lowest in the IF with statistically significant difference. Other studies showed that using a metatarsal pad resulted in mild decreases in PPP at the first and second metatarsal heads (approximately, 12% to 60%), slight increases laterally, and decreases in PTI at the 1st–4th metatarsal heads. However, these previous studies focused on the effectiveness of padding in the metatarsal head region only, not other regions. Unlike other studies, we evaluated specific pressures in other regions to investigate pressure shifting or redistribution. Interestingly, both PPP and PTI were the highest in the 2nd–5th toes and mid region, which manifested burdening of pressure, instead of the forefoot region. Based on our results, it is advised to consider wearing MPI carefully when there are clinical symptoms in the toe and midfoot region.

Previous studies have shown significant results related to valgus moment and pressure shifting in not only the knee joint but also the ankle joint. In our study, IH region in the LHI was significantly higher than that in other types of soles in terms of both PPP and PTI, consistent with a previous study. Additionally, both PPP and PTI were the highest wearing LHI in the cFF and IF regions. Also, pressure with the LHI was significantly higher in the mid region but lower in the heel region than that with the CI, which indicates pressure shifting to the anterior region. Likewise, the reason for this result is later-
alization of COP,\textsuperscript{7} and eventually, LHI is thought to affect varus correction of the hindfoot by valgus moment of the subtalar joint.

Traditionally, ASI was designed to correct biomechanics of the foot and make normal pressure distribution for the flatfoot, which is defined as collapse of the medial longitudinal arch of the foot during walking.\textsuperscript{24} In a systematic review, the flatfoot manifested higher plantar pressure, force, and contact area values in the medial arch, cFF, and hallux, while these variables were lower in the mFF and lFF.\textsuperscript{25} To correct the abnormal load distribution, ASI is commonly prescribed to shift the load from the forefoot and rearfoot toward the midfoot area while the midfoot contact area is increased.\textsuperscript{26} In the mid region, both PPP and PTI were the second highest after MPI when wearing ASI, which means redistribution effect to the mid region.
of ASI was not much greater than that of MPI. Meanwhile, values of related pressure in the IH region were lowest compared to other insoles that make less burden to the IH region. Our result was similar with that in a previous study in that PPP was higher in the mid and first ray, and was lower in the mH, second, and third rays.\textsuperscript{27} It was suggested that the support mechanism of the medial arch shifts the load from the forefoot and hindfoot toward the midfoot and causes increased pressure in this area.\textsuperscript{26} But in our studies, in the mFF region, ASI was the highest and significantly higher than several types of insoles in terms of PPP, which is in line with a previous study.\textsuperscript{27} One of our limitations was not to separate the medial midfoot and lateral midfoot, which would have made it possible to evaluate the effectiveness of ASI precisely. In our study, a part of pressure was shifted to mFF to lessen the burden of the medial midfoot region. It has been suggested that pressure reduction in the heel region may be the result of two structural mechanisms: structure of heel cup that redistributes the pressure and realigns the calcaneus to a more normal location and medial arch support inducing load transfer from the heel to the midfoot region.\textsuperscript{4,26} As a result, ASI is expected to prevent further collapse of the medial longitudinal arch and hyper-pronation, so that tension and force are decreased in the surrounding tendons and soft tissues.

Interestingly, we found that the PTI values of the three types of insoles were consistent relatively with the PPP values. Given that PTI is related to the duration of pressure of the foot, there are clinical significance and several possible explanations for this finding. First, considering a temporal effect, the PTI can provide a better evaluation of the overall pressure loading than the PPP, which is a point estimation. Second, mechanoreceptors have faster responses to increasing pressure than nociceptors.\textsuperscript{28} The short duration of the peak pressure may not be sufficient to provoke firing of high frequency of the nociceptors.\textsuperscript{28,29} Based on our findings, we suggest that the optimal treatment should consider not only PPP but also PTI.

One of the limitations of our study is that we enrolled only men. Due to kinematic and physical structure differences between men and women, the results of the study observed in men without symptoms of the foot and ankle may not be applicable in women without symptoms of the foot and ankle. Second, it is difficult to define participants as asymptomatic people in this study considering that they only underwent radiographic examination used to diagnose flat feet, not studying to rule out presence of other diseases. In addition, insoles can be an effective device for patients with foot and ankle diseases, but as our study did not include a patient group, it is difficult to ensure that the same type of insoles used in our study will have the same influence on patients. But, it could provide a basic and useful clue for an insole study on evaluating pressure patterns in an asymptomatic group. Further research should be undertaken to evaluate the effect of these potential confounders. Finally, we suggest that the redistribution of plantar pressures tended to be related not only to the consistency in dimensions of insoles and foot sizes, but also to anatomic foot configuration and location of an insole.\textsuperscript{30} Knowledge of these parameters, along with careful control of insole dimensions and placement, will allow effective use of the orthotic devices for redistributing forefoot plantar pressures.

This study, which confirmed plantar pressure patterns for each insole type through multiple foot segmental analyses in asymptomatic men, showed that each of the three types of insoles could reduce and redistribute the pressure on a specific part of the foot. Also, it may provide clinicians with useful information on selecting an appropriate insole that optimizes the distribution of plantar pressure patterns for each treatment purpose.

**CONFLICT OF INTEREST**

No potential conflict of interest relevant to this article was reported.

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