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Original Article

Plantar pressures in individuals with normal and pronated feet according to static squat depths

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Abstract. [Purpose] The purpose of the present study was to investigate differences in plantar pressure between individuals with normal and pronated feet according to 3 static squat depths. [Subjects and Methods] Study subjects were 10 young adults with normal and pronated feet. Plantar pressures were measured in the standing position and static squat positions at 45° (semi-squat) and 90° (half-squat) knee flexion using the F-Mat. Subjects' plantar pressures were analyzed by dividing the foot into 4 areas: forefoot medial, forefoot lateral, midfoot, and heel. [Results] In the half-squat position, the pronated foot group showed a higher foot pressure in the forefoot medial than was seen in the normal group, whereas the normal group exhibited a higher foot pressure in the heel than was seen in the pronated foot group. [Conclusion] An increase in squat depth led to the transfer of plantar pressure to the heel in normal feet and to the forefoot medial in pronated feet.
Key words: Plantar pressure, Pronated feet, Squat

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INTRODUCTION

The distribution of plantar pressure has frequently been measured to understand changes in pressure applied to the foot, changes in the center of pressure, and changes in gait pattern caused by foot shapes or problems[1, 2)]. In particular, plantar pressure is widely assessed in diabetic foot studies[3, 4)]. Also, a number of physical therapists use plantar pressure as a tool to evaluate diseases in the foot or lower extremity and on this basis, provide gait training, footwear, and interventions for foot orthoses[5)]. The purposes of previous studies on plantar pressure in the pronated foot include identifying gait differences between pronated and normal feet[2)], examining the effects of customized foot orthoses[6)], and identifying plantar pressure changes according to low-dye taping[7, 8)].

Squats require a combination of functional motions and are an important basic exercise for clinical evaluations and training[9)]. Foot pronation causes changes in movements of the low extremity such as squatting[10, 11)]. Regarding such changes due to foot pronation, existing studies on plantar pressure according to different squat depths remain inadequate. Therefore, the purpose of this study was to identify whether plantar pressure differences exist between normal and pronated feet according to 3 different squat depths.

SUBJECTS AND METHODS

Study subjects were 10 individuals with normal feet (age 21.9±2.7 years, weight 64.9±13.0 kg, height 172.4±5.5 cm, navicular drop [ND] 7.0±1.5 cm) and 10 individuals diagnosed with pronated feet (age 21.3±1.6 years, weight 65.5±9.0 kg, height 171.9±6.8 cm, ND 11.7±1.5 cm). All subjects were provided with an informed consent form, including the study's purpose, methods, and procedures according to the Declaration of Helsinki, and agreed to participate in the study by reading its contents and signing and submitting the form. The navicular drop test (NDT) by Cote et al.[10)] was employed to select the subjects with normal and pronated feet. First, while the subjects were sitting on chairs with their feet placed in the subtalar joint neutral position, the height from the ground of the prominent portion of the navicular tuberosity was measured. Next, while the subjects were in a relaxed standing position, the same measurement was repeated. The difference between the two measured values yielded the ND. On the basis of the NDT's results, subjects with NDs in the range of 5–9 mm were placed in the normal group, and those with NDs in the range of ≥10 mm were placed in the pronated foot group. Those who had experienced pain or undergone an operation for musculoskeletal problems or had a neurologic disease within the preceding 6 months were excluded in the selection process.

The platform-type F-Mat of F-Scan system (Tekscan, Inc., South Boston, MA, USA) was used to measure the pres-

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Table 1. Foot pressures of normal and pronated feet according to 3 static squat depths

Area	Group	ES	SS	HS
FM	Normal foot	61.0±21.2	66.7±31.1	60.9±25.1
	Pronated foot	55.4±17.3	75.6±20.6	104.5±51.0*#
FL	Normal foot	76.4±14.2	81.4±24.5	63.5±15.5
	Pronated foot	63.7±10.0*	74.1±21.3	69.4±21.1
MF	Normal foot	36.0±16.9	32.8±8.9	28.1±10.4
	Pronated foot	29.6±11.2	34.5±16.7	27.5±11.6
Heel	Normal foot	116.4±30.2	144.0±29.0	181.1±33.6#$
	Pronated foot	118.7±36.3	121.7±39.4	115.4±47.2*

Data are presented as mean±SD (kPa). *Significant difference between the two groups, $p < 0.05$; #$p < 0.05$ vs. ESP; $$p < 0.05$ vs. SS
FM: forefoot medial; FL: forefoot lateral; MF: midfoot; ES: erect standing; SS: semi-squat; HS: half-squat

sure applied to the foot. The F-Mat developed by Tekscan is known to offer moderate to good reliability[11]. Plantar pressure was measured in 3 positions: erect standing (ES), semi-squat (SS), and half-squat (HS). All subjects were instructed to stand barefoot with their feet shoulder-width apart on the F-Mat's floor mat.

The ES position referred to looking straight ahead, stretching the knee, and standing straight up. The SS position was defined as performing a squat position at 45° knee flexion, whereas the HS position was defined as performing a squat to reach 90° knee flexion. Subjects were instructed to stretch their arms forward, parallel to the ground. Their knee angles were set using a goniometer. While subjects maintained each squat position in a static manner, their plantar pressures were measured for 6 seconds. Each of the 3 positions, according to different squat depths, was measured 3 times. All measured values of plantar pressure were segmented into 4 foot regions using the software program F-Scan Research TAM/STAM 5.83 (Tekscan, Inc., South Boston, MA, USA). These regions were forefoot medial (FM), forefoot lateral (FL), midfoot (MF), and heel. The forefoot region was divided into medial and lateral regions by the location of the second toe. Peak contact pressures in the 4 regions were determined and used for analysis.

PASW Statistics 18 for Windows (IBM Corp., Armonk, NY, USA) was used for statistical analysis. Comparison of the normal and pronated foot groups was performed using independent t-tests. In addition, a one-way analysis of variance was employed to compare plantar pressures according to different squat depths (ES, SS, and HS). A post-hoc analysis was performed when statistically significant differences were revealed. The statistical significance level was set at $p < 0.05$.

RESULTS

The results of this study are presented in Table 1. In the ES position, a lower plantar pressure in the FL was found in the pronated foot group than in the normal group ($p<0.05$). However, the remaining regions (FM, MF, heel) did not show statistically significant plantar pressure differences between the normal and pronated foot groups ($p>0.05$). In the SS position, no foot regions exhibited statistically significant plantar pressure differences between the normal and pronated foot groups ($p>0.05$). In the HS position, a higher plantar pressure in the FM and a lower plantar pressure in the heel were found in the pronated foot group than in the normal group. The FL and MF did not exhibit statistically significant plantar pressure differences between the normal and pronated foot groups ($p>0.05$). However, the comparison of plantar pressures at different squat depths showed that the FM in the pronated foot group ($p<0.05$) and the heel in the normal group ($p<0.05$) exhibited statistically significant plantar pressure differences according to different squat depths. The post-hoc test confirmed statistically significant plantar pressure differences in the FM of the pronated group between the ES and HS positions ($p<0.05$). In addition, statistically significant plantar pressure differences in the heel of the normal group were exhibited between the ES and HS positions and between the SS and HS positions ($p<0.05$).

DISCUSSION

This study was conducted to understand plantar pressure differences in subjects with normal and pronated feet according to different squat depths. Squat depths are generally classified by the degree of knee flexion, but different researchers apply different terms or ranges. Coqueiro et al.[12] used 45° knee flexion for SSs, whereas Escamilla et al.[13] used 45°, 90°, and maximal knee flexion as their squat depths. On the basis of previous studies, we set the SS position as 45° knee flexion and the HS position as 90° knee flexion.

Researchers use various foot regions for plantar pressure distributions. Some have divided the foot into 7 regions: heel, midfoot, 1st metatarsophalangeal joint (MPJ), 2nd MPJ, 3rd–5th MPJs, hallux, and lesser toes[11], and others have designated 10 foot regions by further segmenting the mid-foot and heel in addition to the above 7 areas[14]. Alternatively, some investigators have divided the foot into 4 regions: FM, FL, MF, and heel[15]. In the present study, plantar pressures were analyzed by dividing the foot into 4 regions according to the method of Braz & Carvalho[15].

Braz & Carvalho[15] analyzed plantar pressure in professional soccer players and ordinary people. When the subjects

were standing upright, ordinary people showed right-foot plantar pressures of 0.5±0.2 (kg/cm^2) in the FM, 0.6±0.2 (kg/cm^2) in the FL, 0.5±0.2 (kg/cm^2) in the MF, and 1.3±0.4 (kg/cm^2) in the heel. In the present study, the normal group yielded plantar pressures of 61.0±21.2 (kPa) in the FM, 76.4±14.2 (kPa) in the FL, and 116.4±30.2 (kPa) in the heel. Therefore, pressures similar to those in the previous study were revealed except in the MF (1 kg/cm^2 ≈ 98 kPa).

In the present study in the normal group, an increase in squat depth led to an increase in plantar pressure in the heel. However, the pronated foot group did not show differences. During HS, this group rather exhibited a higher plantar pressure in the FM than was seen in the normal group. In the pronated foot group, an increase in squat depth by moving from the ES position to the HS position resulted in an increase in plantar pressure in the FM. In an earlier study, Teh et al.[14] assessed plantar distributions in the feet of obese and non-obese subjects and reported that the obese group showed a higher peak pressure in the forefoot and a lower peak pressure in the heel than was found in the normal group. The obese group was thought to have a higher peak pressure in the forefoot because weight bearing in the obese individuals caused structural deformations in which the foot's medial longitudinal arch was destroyed. The present study may have had a similar mechanism. An increase in squat depth resulted in an increase in ankle dorsiflexion in subjects with pronated feet. This eliminated the medial longitudinal arch, thereby increasing weight loads in the FM.

Our study had certain limitations. The number of subjects was small, and the performance of squats using both feet reduced weight loads applied to the feet. Therefore, additional studies should examine squats using a single foot. However, this study confirmed that an increase in squat depth led to an excessive increase in plantar pressure in the FM of pronated feet compared with the increased pressure in the FM of normal feet. Therefore, during squat exercises, individuals with pronated feet may need to make proper weight shifts and use insoles to control foot pronation. They should also avoid exercises that use squatting positions beyond HS. This study is expected to be the basis for designing a method for people with foot pronation to safely perform squat movements.

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