Original Article

The kinematics of the lower leg in the sagittal plane during downward squatting in persons with pronated feet

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Abstract. [Purpose] This study aimed to examine changes in lower extremity kinematics in the sagittal plane during downward squatting by subjects with pronated feet. [Subjects and Methods] This study selected 10 subjects each with normal and pronated feet using a navicular drop test. The subjects performed downward squatting, in which the knee joints flex 90° in a standing position. We recorded the angles of the hip, knee, and ankle joint in the sagittal plane through motion analysis. For the analysis, the squatting phase was divided into phase 1 (initial squat), phase 2 (middle squat), and phase 3 (terminal squat) according to the timing of downward squatting. [Results] In the pronated foot group comparison with the normal group, the hip joint flexion angle decreased significantly in phases 2 and 3. The dorsiflexion angle of the ankle joint increased significantly in phase 3. The flexion angle of the knee joint did not differ between groups in any of the phases. [Conclusion] The pronated foot group utilized a different squat movement strategy from that of the normal foot group in the sagittal plane.
Key words: Pronated foot, Kinematics, Squat

INTRODUCTION

The feet are a very important tool for movement and exercise in humans who walk erect. One of the most common biomechanical problems with feet is abnormal pronation[1]. Excessive pronation of the feet is related to diverse overuse injuries of the lower limbs[2–4] and is considered a cause of proximal biomechanical dysfunction[2, 4]. Excessive pronation of the feet increases the risk of valgus knees and triggers internal rotation of the hip joint[1]. Hyperpronation of the feet causes immediate internal rotation of the shank and thighs and a change in pelvic position, which contributes to lower back dysfunction[5]. Changes in foot structure, such as pronation and supination, affect the static and dynamic postural stability[6].

Squatting is associated with various lifting motions in the activities of daily living, and it is one of the exercises used most frequently for strength and conditioning[7]. Previous studies on pronated feet have largely focused on kinematic changes in the gait or activities such as running[2]. Recently, there was a study regarding the effects of short-foot ex-ercise on the dynamic balance of subjects with pronated feet[8]. However, the effects of pronated feet on lower limb movements in the sagittal plane during squatting remain unclear. Accordingly, this study examined differences in the kinematic variables of the lower limbs that occurred in the sagittal plane between a pronated foot group and a normal foot group.

SUBJECTS AND METHODS

Subjects

Ten young male adults each with pronated and normal feet participated in this study. Table 1 presents the general characteristic of the participants. All subjects performed a navicular drop test (NDT). We measured the navicular height, the distance between the tubercle of the navicular bone and the floor in sitting (subtalar neutral position) and standing (full weight bearing position) positions. The navicular drop is the difference between the two distances. The normal value for navicular drop is between 5–9 mm[6]. Therefore, participants with a navicular drop exceeding 9 mm were included from the pronated foot group. Subjects were excluded from the study group if they had reported any pain in the lower extremities during physical activity or squatting or suffered from neurological symptoms or restricted range of motion. All participants understood the purpose of this study and provided written informed consent prior to participation in accordance with the ethical standards of the Declaration of Helsinki.

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Methods

We measured the joint angle of the hip, knee, and ankle in the sagittal plane using motion analysis (EGL-500RT, Motion Analysis Corp, Santa Rosa, CA, USA). We attached reflective markers (10 mm) to the trunk and anterior superior iliac spine (ASIS); thigh, medial and lateral epicondyle of the femur, and lower leg; medial and lateral malleolus; and 2nd metatarsal head of the subjects according to the Helen Hayes marker set. Squatting was initiated while the subjects flexed the arms at 90° when standing in a shoulder-width stance. While conducting the motion, the subjects kept their trunk upright. The movement range for squatting was set as being until the knee joint flexion angle became 90° in an upright standing position. The movement speed was controlled according to a metronome such that the subjects conducted squatting for 3 seconds. In the present study, downward squatting was divided into three phases according to the timing of knee flexion movements: phase 1, when the subjects started squatting, was immediately before they initiated movement in an upright position (initial squat); phase 2 was the middle point of the squat (middle squat); and phase 3 was the last point of the squat (terminal squat). The angles of the hip, knee, and ankle joint in the sagittal plane according to these phases were extracted, and the average values of three repeated movements were used for analysis.

A statistical analysis was performed using PASW Statistics version 18 for Windows. Descriptive statistics were analyzed for the characteristics of the participants (including age, height, weight, NDT). An independent t-test was used for comparing the differences of each angle of a hip, knee, and ankle joint in the normal and pronated foot groups according to the squat phase—phase 1, phase 2, or phase 3—in the sagittal plane. The criterion for statistical significance was set at the level of $p < 0.05$.

Table 1. General characteristics of the participants

	Normal foot (n=10)	Pronated foot (n=10)
Age (year)	21.9±2.7	21.3±1.6
Weight (kg)	64.9±13.0	65.5±9.0
Height (cm)	172.4±5.5	171.9±6.8
NDT (mm)	7.0±1.5	11.7±1.5

Values are means±SD. NDT: navicular drop test

RESULTS

Table 2 shows a summary of the changes in the joint angles of the lower extremity attained during downward squatting. The results of t-tests showed no significant changes in the knee flexion angles between the groups in each phase during downward squatting ($p > 0.05$). The hip flexion angle showed statistically significant differences, with that of the pronated foot group being significantly less than that of the normal group in phase 2 ($p < 0.05$) and phase 3 ($p < 0.01$); no significant changes were noted in phase 1 ($p > 0.05$). Furthermore, the ankle dorsiflexion angle showed a statistically significant difference, with that of the pronated foot group being significantly larger than that of the normal group in phase 3 ($p < 0.05$); no significant changes were noted in phase 1 and phase 2 ($p > 0.05$).

DISCUSSION

This study was conducted to comparatively analyze the characteristic changes in the lower limb joint movements of subjects with pronated feet in the sagittal plane during squatting through motion analysis. A squat is generally classified into three groups according to the knee flexion angle: a partial squat is when the knee flexion angle is ~40°, a half squat is when the knee flexion angle is between 70° and 100°, and a deep squat is when the knee flexion angle exceeds 100°[7]. In this study, a knee flexion angle of 90°, i.e., a half squat, which is most frequently used in the clinical field, was measured.

In a dynamic squat, a person starts in an upright standing position with the knee and hip joints extended and then squats down by flexing at the hip, knee, and ankle joints[7]. Escamilla et al.[9] noted that during a squat, the knees and hip were flexed and extended in a similar form and to a similar extent, and the shanks was similar to the movement form and extent of the trunk. In the present study, the flexion angles of the normal group's hip and knee joints were identified: 16.39° and 13.44°, respectively, during phase 1; 51.26° and 55.07°, respectively, during phase 2; and 89.53° and 97.68°, respectively, during phase 3, with movements to a similar extent. As the subjects progressed from phase 2 to phase 3, the pronated foot group's hip joint flexion angle (38.1°, 71.6°) was statistically lower than that of the normal foot group (51.26°, 89.53°). Graci et al.[10] examined gender differences in the kinematics of the lower extremities during

Table 2. Joint angles of the lower extremity in the sagittal plane during downward squatting

		Phase 1	Phase 2	Phase 3
Hip flexion (°)	Normal foot	16.4±6.3	51.3±12.0	89.5±9.5
	Pronated foot	11.9±5.8	38.1±13.0*	71.6±16.1**
Knee flexion (°)	Normal foot	13.4±4.8	55.1±4.0	97.7±7.6
	Pronated foot	9.6±7.4	51.7±3.9	94.9±5.8
Ankle dorsiflexion (°)	Normal foot	4.4±2.6	17.6±2.6	25.2±4.4
	Pronated foot	3.0±2.6	18.7±4.0	30.5±6.7*

Values are means±SD. * $p < 0.05$; ** $p < 0.01$
Phase 1, initial squat; phase 2, middle squat; phase 3, terminal squat

a single leg squat. They observed that females showed lesser trunk flexion and greater knee abduction than males. Both genders used different movement strategies during single leg squat. The result in our study was similar to their study result, although without the gender differences. The pronated foot group showed lower hip flexion angles than the normal group. Gribble et al.[11] reported that chronic ankle instability and fatigue disrupt dynamic postural control, altering control of sagittal-plane joint angles proximal to the ankle. These results are consistent with our hypothesis. It may be possible that pronated feet increase ankle mobility and internal rotation of the lower limbs, restrictively affecting hip joint flexion movements.

In the present study, a comparison of ankle movement showed that the ankle dorsiflexion angle was significantly greater in the pronated foot group (30.49°) than in the normal group (25.15°) during phase 3. When there was no shortening of the soleus, pronation of the feet increased flexibility in the ankles[1]. Power and Clifford[12] examined the effects of rearfoot position on squat kinematics in healthy adults with pronated feet. According to their results, the peak ankle dorsiflexion angle was significantly reduced in the group whose pronated feet were corrected to a subtalar neutral position compared to barefoot. The present study showed a similar result. The angle of the pronated foot group was probably greater than that of the normal group because as squatting progressed, pronation in the pronated group became more severe, increasing the mobility of ankle dorsiflexion and reducing the movement of the hip joint relative to the those of the normal group, thereby leading to more ankle movement to compensate for the reduced movement.

The limitations of this study are that the number of subjects was small and that they were all young males. Therefore, future research needs to study a large number of subjects of different ages and genders.

In conclusion, the ankle and hip joint movements during squatting are considered to have a certain relation, and it was found that the pronated foot group used a different squat strategy compared with the normal group. Also, excessive ankle movement in persons with pronated feet may cause injury to their feet. As a result, control of ankle and hip joint movement is important in people with pronated feet while squatting, especially in the half squat. Thus, to prevent damage during squatting exercises, people with pronated feet need to modify their exercise strategy and correct their pronated feet or perform exercises to correct them.

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