A prospective study of the muscle strength and reaction time of the quadriceps, hamstring, and gastrocnemius muscles in patients with plantar fasciitis

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Research article

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Abstract

Background: Muscle weakness has been reported to be an important etiological factor in plantar fasciitis (PF), but the data available in the quadriceps, hamstring, gastrocnemius (GCM) muscles is limited . The aim of the study was to compare the strength and reaction time of the quadriceps, hamstring, and gastrocnemius (GCM) muscles and foot pressure between patients with PF and normal controls.

Methods: 21 PF patients and 21 normal controls were registered. Muscle strength was measured by the peak torque per body weight (Nm kg^{-1} × 100). Muscle reaction time was evaluated by the acceleration time (AT, milliseconds). Foot pressure and posture were assessed by pedobarography [valgus/varus index (VV index), %].

Results: The strength of the quadriceps was significantly decreased in the affected ankles of the PF group than in the control group (p=0.005). The AT of the quadriceps and hamstring muscles was significantly increased in the affected ankles of the PF group than in the control group (quadriceps: p=0.012, hamstring: p=0.001), while the AT of the GCM muscle was significantly decreased (p=0.009) and was significantly negatively correlated with quadriceps muscle strength (r=-.598, p = .004) and AT (r=-.472, p=.031). Forefoot (p=0.001) and hindfoot (p=0.000) pressure were significantly greater, with the VV index showing hindfoot valgus, in the affected ankles of the PF group when compared to those of the control group (p=0.039).

Conclusion: This study demonstrated weakness and delayed reaction time of the quadriceps and hamstring muscles, with a rapid reaction time of the GCM muscle, in PF patients.

Clinical Relevance: Clinicians and therapists should assess the function of the quadriceps and hamstring muscles when planning the management of PF patients without muscle tightness.

Background

Plantar fasciitis (PF) is the most common problem involving foot pain. The causes of PF include excessive physical activities,[1] obesity,[2] age,[3] prolonged standing,[2] altered biomechanics,[4,5] limited ankle dorsiflexion with foot postures such as pes cavus and pes planus,[6] and hamstring tightness.[7] Among them, limited ankle dorsiflexion is caused by gastrocnemius (GCM) tightness, which may increase the stress to the plantar fascia because it affects the alignment of the calcaneal bone.[8] Hamstring tightness may induce prolonged loading in the forefoot, which can result in increased repetitive stress on the plantar fascia.[7,9] Therefore, most therapists have focused on restoring the flexibility of the posterior muscles such as the GCM and hamstring in PF patients.

Weakness of the GCM[5] and proximal muscles,[5,10] such as the gluteal muscles and tensor fascia latae, in patients with PF has been reported, which may impact the plantar fascia load distribution. Recently, a systematic review reported that intrinsic musculature strength is associated with the symptoms of PF.[11] Furthermore, a recent study by Lee et al.[5] reported that increased foot pressure in patients with PF may be associated with weakness of the GCM and hip muscles. Therefore, muscle weakness may be an important etiological factor in PF. To date, however, no study has yet investigated the proximal muscles such as the hamstring and quadriceps muscles in terms of strength and reaction time in patients with PF, though these muscles play a role in the alteration of lower extremity biomechanics[12-15] and may contribute to increased plantar fascia load.

The purpose of this study was to analyze differences in the strength and reaction time of the quadriceps, hamstring, and GCM muscles, as well as foot pressure and posture, between patients with PF and normal controls. We hypothesized that the PF patients would show decreased strength and delayed reaction time of the quadriceps, hamstring, and GCM muscles and increased foot pressure compared to normal controls.

Methods

Participants

This study was approved by our institutional review board; all study participants provided informed consent, and the rights of the subjects were protected. This prospective case-control study enrolled 112 patients with foot pain at our institute from July 2018 to November 2019. Physical examinations and evaluations of all images were independently performed by two experienced surgeons. Any disagreements on the PF were resolved by consensus. In the present study, the inclusion criteria were PF patients with normal foot posture in terms of the naviculocuboid overlap and talonavicular coverage angle on plain radiographs, without tightness of the GCM or hamstring muscles. We excluded 91 patients for the following reasons (Fig. 1): pain in both feet, metatarsalgia, Morton neuroma, calcaneal spur, pes cavus and pes planus, and tightness of the GCM and hamstring muscles in the Silfverskiold and popliteal angle tests, respectively. We also excluded patients who had received a steroid injection within 6 months or had undergone knee surgery within 1 year. Of the 112 patients, 91 were excluded; thus, 21 patients were finally enrolled. The 21 normal control subjects selected from our database of volunteers had no history of lower extremity injury symptoms and agreed to participate in the present study.

Assessment of isokinetic muscle performances

Muscle strength of the quadriceps and hamstring

Isokinetic knee extension/flexion strength (concentric/concentric mode, Nm $kg^{-1} \times 100$) was measured in a sitting position with 90° flexion of the hips and knee joints on a dynamometer. Flexion and extension strength was considered to represent hamstring and quadriceps strength, respectively. Each test consisted of 5 repetitions of flexion/extension (ROM, 90° to 0°) for each leg at 60°/s.

Muscle strength of the GCM

Isokinetic GCM strength (concentric mode, Nm kg^{-1} × 100) was measured in a semi-seated position with 20° of knee flexion[16] on a dynamometer, with 5 repetitions of plantar flexion for each leg at 30°/s.

Assessment of the muscle reaction time (acceleration time)

Muscle reaction time was measured by the acceleration time (AT) during isokinetic strength testing, defined as the muscle reaction time (msec) to attain the pre-set angular velocity (60°/s for the knee joint and 30°/s for the ankle joint) during maximal muscle contraction. Lower AT values signify rapid muscle reaction ability[17-19]. The AT was calculated automatically by the Biodex advantage software.

Assessment of the foot pressure and posture

Foot pressure was measured by pedobarography[5,20,21] (Tekscan, Massachusetts) during a 2-meter walk and recorded at 50 Hz. Based on a previous study,[21] the peak pressure and pressure-time integral were calculated for each of the 5 segments of the foot (Fig. 2): the medial forefoot (MFF), lateral forefoot (LFF), medial midfoot (MMF), lateral midfoot (LMF), and heel. These data were processed to yield the valgus/varus index (VV index, %), which is defined as ((MMF + MFF) - (LMF + LFF))/(MMF + MFF + LFF +LMF), with plus (+) and minus (-) values of the VV index indicating hindfoot valgus and varus, respectively.[21] The same peak pressure and VV index assessment processes were used for the normal controls.

Statistical analysis

The sample size calculation for the present study was based on a previous study of muscle strength in patients with lower extremity injuries,[19,22] and a muscle strength difference >10% between the groups was considered significant. To determine the sample size, we conducted a priori power analysis, with an alpha level of 0.05 and a power of 0.8. Effect size (Cohen's d: 1.00) was calculated using the mean and standard deviation from the results of a pilot study involving 5 ankles in each group; 17 ankles in each group were required to adequately identify a clinically meaningful difference >10% in muscle strength between the groups. The power necessary to detect differences in muscle strength was 0.813.

The Student's *t*-test was used to compare the strength and reaction time of the quadriceps, hamstring, and GCM and the foot pressure and posture between the patients with PF and normal controls. To determine whether a continuous variable followed a normal distribution, the Shapiro test was used. Correlations between the strength and reaction time of the quadriceps, hamstring, and GCM muscles were assessed by Pearson's coefficient of correlation. Data were analyzed using SPSS software version 17.0 (SPSS Inc., Chicago, IL, USA). A value of $p < 0.05$ was considered statistically significant.

Results

Table 1 shows the demographic data of the PF patients and normal controls, with no differences between the two groups.

Table 1. Demographic data in enrolled patients with plantar fasciitis and normal controls.

	PF patients group (n = 21)	Normal control group (n = 21)	*p*-value
Gender (male/female)	10/11	13/8	
Age (years) [a]	53 ± 4	51 ± 7	0.342
Height (cm) [a]	168 ± 3	166 ± 6	0.697
Weight (kg) [a]	66 ± 7	68 ± 4	0.778
Sports and activity, n (low:high)	18:3	16:5	0.401

Abbreviations: PF: plantar fasciitis.

[a]The values are expressed as mean ± standard deviation.

Isokinetic strength

The strength of the quadriceps, but not the hamstring or GCM ($p > 0.05$, Table 2), was significantly decreased in the affected ankles of the patients with PF compared with those of the normal controls (115 ± 34.7 vs. 144 ± 26.1, respectively; $p = 0.005$, Table 2).

Table 2. Comparison of muscle strength and acceleration time in both ankles between the patients with plantar fasciitis and normal controls.

	Affected ankles			Unaffected ankles		
	PF patients group	Normal control group	*p*-value	PF patients group	Normal control group	*p*-value
GCM strength	30 ± 11.4	41 ± 14.4	0.278	37 ± 10.9	41 ± 11.5	0.633
Quadriceps strength	115 ± 34.7	144 ± 26.1	**0.005** [a]	126 ± 34.8	141 ± 21.9	0.110
Hamstring strength	61 ± 20.4	68 ± 12.7	0.182	74 ± 16.9	77 ± 8.2	0.370
GCM AT	30 ± 11.4	41 ± 14.4	**0.009** [a]	37 ± 10.9	41 ± 11.5	0.278
Quadriceps AT	64 ± 25.2	48 ± 14.4	**0.012** [a]	54 ± 25.2	51 ± 14	0.652
Hamstring AT	77 ± 21.9	56 ± 15.6	**0.001** [a]	60 ± 13.7	58 ± 17.7	0.629
Forefoot pressure	70 ± 27.7	46 ± 15.7	**0.001** [a]	52 ± 18.7	46 ± 15.7	0.277
Hindfoot pressure	65 ± 22.8	36 ± 15.2	**0.000** [a]	44 ± 18.6	36 ± 15.2	0.115
Foot posture (VV index)	0.2 ± 0.3	0 ± 0.2	**0.039** [a]	-0.1 ± 0.3	0 ± 0.2	0.861

Abbreviations: PF: plantar fasciitis, GCM: gastrocnemius, AT: acceleration time, VV index: valgus/varus index.

Note: The values are expressed as mean ± standard deviation

Measurement units for muscle strength and muscle reaction time were Nm kg^{-1} × 100 and milliseconds, respectively.

[a]**Statistically significant**

Muscle reaction time (AT)

The AT of the hamstring and quadriceps muscles was significantly greater in the affected ankles of the PF group than in those of the control group (hamstring: 77 ± 21.9 vs. 56 ± 15.6, *p* = 0.001, quadriceps: 64

± 25.2 vs. 48 ± 14.4, $p = 0.012$, Table 2), whereas the AT of the GCM muscle was significantly lower in the PF patients than in the normal controls (30 ± 11.4 vs. 41 ± 14.4, $p = 0.009$, Table 2).

Correlations between the strength and reaction time of the quadriceps, hamstring, and GCM muscles

The strength of the GCM muscle in the affected ankles showed a significant positive correlation with the strength of the hamstring muscle (r = .634, $p = .002$, Table 3) but not of the quadriceps muscles ($p > 0.05$, Table 3). The AT of the GCM muscle in the affected ankles showed a significant negative correlation with the strength (r = -.598, $p = .004$, Table 3) and AT (r = -.472, p = .031, Table 3) of the quadriceps muscle but not the hamstring muscle ($p > 0.05$, Table 3).

Table 3. Correlations between the muscle strength and muscle reaction time.

Parameters		Affected ankles		Unaffected ankles	
		GCM strength	GCM AT	GCM strength	GCM AT
Quadriceps strength	PCC (r)	.289	-.598	.277	-252
	p-value	.204	**.004** [a]	.225	.271
Hamstring strength	PCC (r)	.634	-.371	.632	-.113
	p-value	**.002** [a]	.098	**.002** [a]	.627
Quadriceps AT	PCC (r)	-.533	-.472	-.189	.080
	p-value	**.013** [a]	**.031** [a]	.412	.732
Hamstring AT	PCC (r)	-.357	.212	.213	-.351
	p-value	.112	.356	.354	.119

Abbreviations: PCC: Pearson’s correlation coefficient, GCM: gastrocnemius, AT: acceleration time.

[a]**Statistically significant**

Foot pressure and posture (VV index)

Forefoot and hindfoot pressure were significantly greater in the affected ankles of the patients with PF than in those of the normal controls (forefoot: 70 ± 27.7 vs. 46 ± 15.7, $p = 0.001$, heel: 65 ± 22.8 vs. 36 ± 15.2, respectively; $p = 0.000$, Table 2). The VV index values indicated hindfoot valgus in the affected ankles of the patients with PF compared with those of the normal controls (+0.2 ± 0.3 vs. 0 ± 0.2, respectively; $p = 0.039$, Table 2).

In the unaffected ankles, there were no significant differences in the strength and reaction time of the quadriceps, hamstring, and GCM muscles or the foot pressure and posture between the PF group and the control group ($p > 0.05$, Table 2).

Discussion

The most important result of the present study was that quadriceps weakness, delayed reaction time of the hamstring and quadriceps muscles, and rapid reaction time of the GCM muscle were all demonstrated in the affected ankles of the PF patients compared with those of the normal controls. The reaction time of the GCM muscle also showed a significant negative correlation with the strength and reaction time of the quadriceps muscle. Furthermore, foot pressure at the forefoot and hindfoot were significantly increased, and the affected ankles of the patients with PF showed hindfoot valgus compared with those of the normal controls.

Weakness of the GCM in patients with PF has been reported.[5,23] However, these studies investigated patients with PF with concurrent tightness of GCM muscle. Therefore, the previous studies were limited because muscle length directly affects muscle strength.[24] In the present study, however, the PF patients without muscle tightness showed weakness of the quadriceps, with no significant difference in the strength of the hamstring and GCM muscles between groups. Although the reason for these results is unclear, it may be explained by the use of compensatory movement strategies for reducing foot pain. During the gait cycle,[25] the foot posture changes from supination to pronation during the change in phase from heel strike to weight acceptance. In patients with PF, foot pain may be incurred by a stretched plantar fascia in the pronated foot;[25] as a result, they may use compensatory movement strategies such as rapid hip flexion to reduce foot pain. In the weight acceptance phase, the quadriceps, hamstring, and GCM muscles, and especially the quadriceps, are highly active in stabilizing the hip and knee joints against gravity and weight.[13,14,24] However, in PF patients, quadriceps function may be gradually reduced by an insufficient weight transfer due to such compensatory strategies, thereby resulting in quadriceps muscle weakness. Another possible explanation is overuse of the hip flexion movement used to reduce the foot pain caused by a stretched plantar fascia. The quadriceps muscle is a hip flexor, and weakness in this muscle may result from its overuse[26,27] in an effort to reduce foot pain. Previous studies have reported that decreased quadriceps strength can lead to increased plantar fascia load and decreased pronation control of the foot,[25,28] thereby increasing foot pain. Further prospective studies are necessary to elucidate the results of PF patients in the present study.

In the PF patients in this study, the reaction time of the hamstring and quadriceps muscles was delayed, whereas the reaction time of the GCM muscle was rapid compared with that of the control group. We believe that these results may be attributable to joint stabilization strategies in the lower extremity. Muscle reaction can be defined as the muscle recruitment capacity for joint stability while performing a functional task;[29,30] thus, rapid muscle reaction time is an important factor for increased joint stability.[30,31] The quadriceps, hamstring, and GCM muscles all contribute to the stability of the knee joint. Lloyd & Buchanan reported that the co-contraction of the quadriceps and hamstring muscles directly supports the valgus/varus moments at the knee joint.[32] The valgus and varus moments of the knee joint can impact foot pronation and supination, respectively,[33-35] which may increase plantar fascia stress owing to increased pressure in the forefoot and hindfoot.[20] In the PF patients in the present study, the hamstring and quadriceps muscles showed a delayed reaction time, with greater pressure in the forefoot and hindfoot and hindfoot valgus on pedobarography, despite normal feet on plain radiographs, compared to the normal control group. Hence, functional abnormalities of the hamstring and quadriceps muscles may contribute to increased pressure in the forefoot and hindfoot. In particular, the reaction time of the GCM muscle showed a significant negative correlation with the strength and reaction time of the quadriceps muscles in this study. Therefore, we believe that the GCM muscle may respond rapidly to support the valgus/varus moments in patients with PF whose hamstring and quadriceps muscles have a delayed reaction time. Previous studies have also reported that the GCM muscle plays an important role in supporting the frontal plane knee alignment (valgus/varus moments) at the knee joint.[32,36] Kvist and Gillquist[37] and Meunier et al.[38] reported that the GCM muscle is neurologically connected to the quadriceps muscle. Consequently, we believe that the reaction time of the hamstring and quadriceps muscles should be assessed and improved, as necessary, in patients with PF.

There were several limitations in the present study. First, the strength of gluteal hip muscles such as the hip abductors was not evaluated in the present study even though previous studies[5,10,39] have reported that hip muscle strength is closely related to foot pain. Second, postrehabilitation results were not included in the correlation analysis. To confirm that the functional abnormalities of the hamstring and quadriceps muscles shown in our results represent a definite etiology of PF in patients without tightness of the GCM and hamstring muscles, further evaluations should occur following rehabilitation of the quadriceps and hamstring muscles.

Conclusions

This study demonstrated weakness and delayed reaction time of the hamstring and quadriceps muscles and a rapid reaction time of the GCM muscle in patients with PF. Clinicians and therapists should aim to evaluate and improve the functionality of these muscles in patients with PF.

List Of Abbreviations

Plantar fasciitis (PF); Gastrocnemius (GCM); Acceleration time (AT); Medial forefoot (MFF), Lateral forefoot (LFF); Medial midfoot (MMF); Lateral midfoot (LMF); Valgus/varus index (VV index).

Declarations

Ethics approval and consent to participate:

The study protocol was approved by Korea University Anam Hospital Institutional Review Board (No: 2018AN0168). All study participants provided informed consent.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions:

JHL and WYJ collected and analyzed the patient clinical data. JHL and WYJ interpreted data and were major contributors to writing the manuscript. All authors read and approved the final manuscript.

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Figures

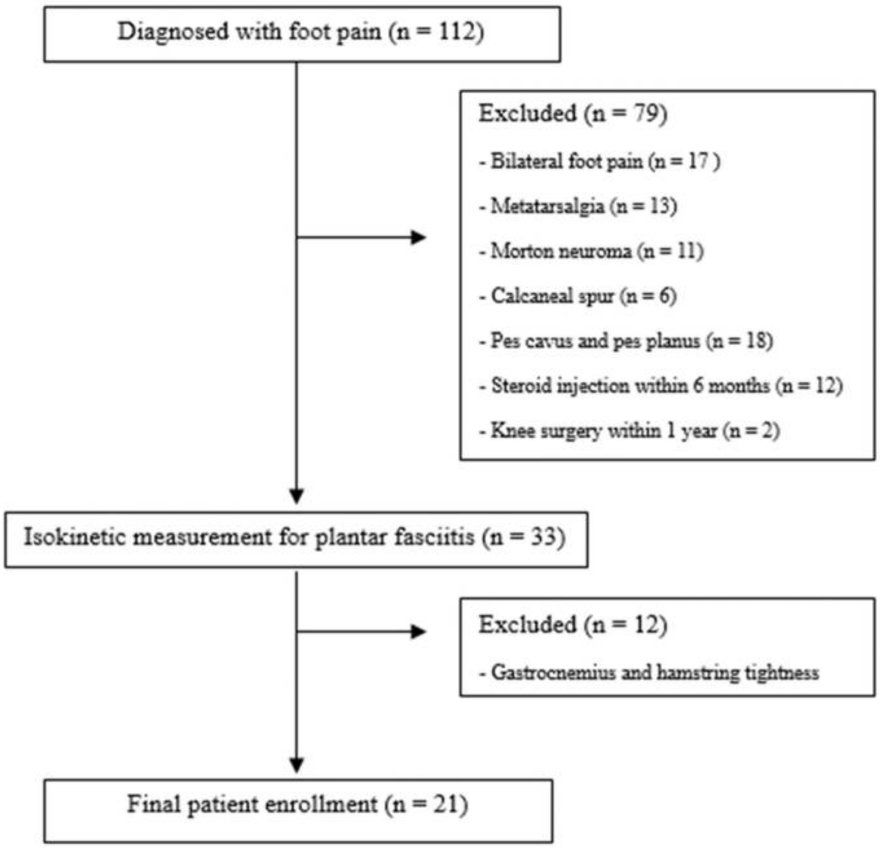

Figure 1

Flowchart of patients with plantar fasciitis.

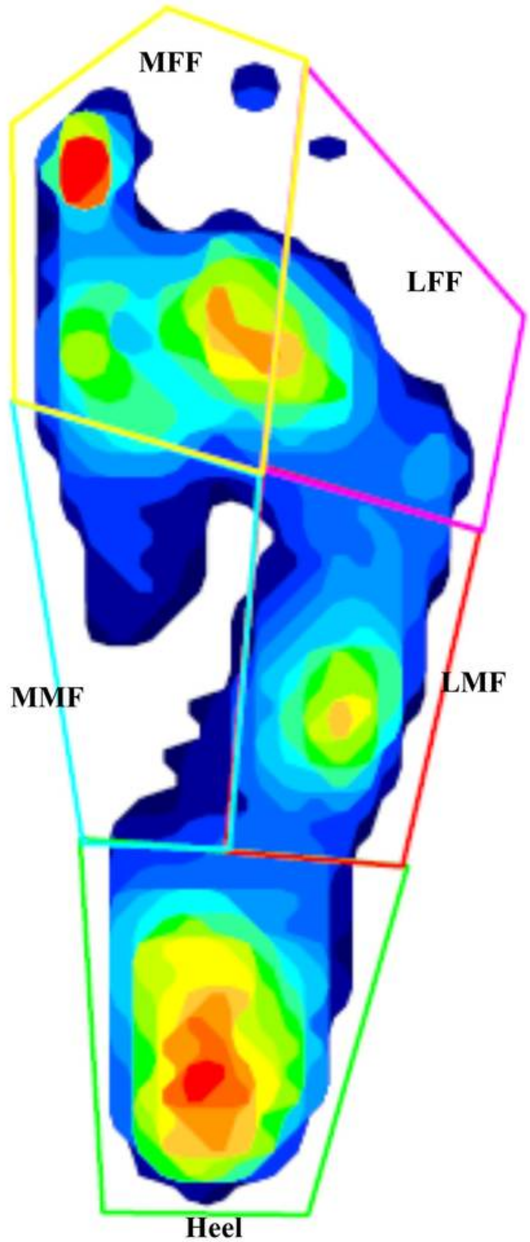

Figure 2

Five segments on pedobarography: the medial forefoot (MFF), lateral forefoot (LFF), medial midfoot (MMF), lateral midfoot (LMF), and heel. This image shows the hindfoot valgus with increased pressure in the forefoot and hindfoot.