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Research article

Changes of Gait Parameters and Lower Limb Dynamics in Recreational Runners with Achilles Tendinopathy

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Abstract
This study aimed to clarify the mechanical gait changes caused by achilles tendinopathy by comparing gait parameters and changes in hip, knee, and ankle moments between an experimental group (EG) and a control group (CG). Twenty runners with achilles tendinopathy were included in the EG (male/female: 10/10, age: 27.00 ± 4.63), and 20 CG (male/female: 10/10, age: 27.25 ± 4.33) participants were recruited. Subjects walked a 13-m distance at their normal walking speed 5 times to obtain motion analysis and joint moment data. Gait parameter analysis showed significant differences in double-limb support (EG: 22.65 ± 4.26%, CG: 20.37 ± 4.46%), step length (EG: 0.58 ± 0.0 7m, CG: 0.64 ± 0.08 m), step width (EG: 0.16 ± 0.04 m, CG: 0.14 ± 0.05 m), stride time (EG: 1.09 ± 0.10 second, CG: 1.05 ± 0.08 second), and walking speed (EG: 1.09±0.18 $m \cdot s^{-1}$, CG: 1.23 ± 0.17 $m \cdot s^{-1}$) between the 2 groups ($p < 0.05$). Significant differences were found in hip joint moment for initial contact, mid-stance, terminal stance, and pre-swing phases; knee joint moment for initial contact and pre-swing phases; and ankle joint moment for pre-swing and terminal swing phases ($p < 0.05$). Gait parameters and hip, knee, and ankle moments were altered in runners with achilles tendinopathy. Thus, clinical features of gait changes should be understood for optimal treatment of achilles tendinopathy; further research is required in this field.

Key words: Achilles tendinopathy, gait, lower limb dynamics, motion analysis.

Introduction

Achilles tendinopathy is one of the most common sports injuries caused by overuse syndrome (Maffulli et al., 2003; Magnussen et al., 2009). The injury rate of this condition has been reported to be approximately 7–9% in elite athletes and 6–18% in individuals who run regularly (Schepsis et al., 2002; Sorosky et al., 2004). Achilles tendinopathy is a condition that can occur in almost every sporting activity, with something along the lines of high incidences occur in activities that involve repetitive training loads (Woods et al., 2002).

The achilles tendon is a conjoint tendon composed of the insertions of the gastrocnemius and soleus muscles on the posterior calcaneus; it is approximately 15 cm in length and comprises equal proportions of the fibers of the gastrocnemius and soleus muscles. Achilles tendinopathy is accompanied by symptoms such as swelling, discoloration, changes of consistency, vascularization, and nodules (Knobloch et al., 2006), as well as an increase in the concentration of neurotransmitters such as glutamate, which causes pain and influences gait (Alfredson et al., 1999).

Two recent studies have assessed kinematic changes in gait in patients with achilles tendinopathy. Ryan et al. (2009) reported that the eversion movement of the subtalar joint increases and that the speed of dorsiflexion decreases, and Azevedo et al. (2009) reported that a decrease in knee range can be observed from initial contact to mid-stance phases and that electromyography (EMG) activation is decreased in the rectus femoris and gastrocnemius muscles.

Although running is an endurance sport that has many merits (Lee et al., 2012), such as increasing cardiopulmonary function and preventing obesity and other adult diseases, negative results from overuse, such as musculoskeletal disorders, are becoming more prevalent; therefore, means of preventing achilles tendinopathy while exercising regularly are required. Recently, as the number of individuals participating in running and other sporting activities has increased, the prevalence rate of achilles tendinopathy has also increased; when the condition occurs, it is considered a factor that hinders the participation in sports (McKean et al., 2006). A previous prospective study has shown that endurance exercises performed over a long period increase the prevalence rate of achilles tendinopathy (Cosca and Navazio, 2007). To achieve this aim, analysis of the gait movement features of runners with and without achilles tendinopathy using quantitative evaluation tools should be performed; however, studies of changes in gait or running posture in achilles tendinopathy patients are minimal.

Thus, this study was aimed at clarifying the mechanical changes in gait caused by achilles tendinopathy by comparing gait parameters and changes in hip, knee, and ankle moments between an experimental group (EG), constituting achilles tendinopathy patients with running experience of more than 1 year, and a control group (CG) of individuals of similar age and physical condition.

Methods

Subjects

This study included 20 participants in the EG, which comprised 10 men and 10 women with chronic achilles tendinopathy (onset period: 7.67±1.64 month) and running experience of more than 1 year, as well as 20 participants in the CG, which comprised individuals of similar age and physical condition compared with those in the

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EG. Subjects were recruited from the K Rehabilitation Hospital Research Center located in Seoul (Table 1). The inclusion criteria for EG patients were a diagnosis of achilles tendinopathy based on structural abnormalities found on only one side by sonography, achilles tendinopathy for at least 6 months, availability for outpatient follow–up, and ability to achieve independent gait without assistant devices.

Table 1. Subject characteristics. Values are means (±Standard Deviation).

	EG	CG
Sex (male/female)	10/10	10 / 10
Injury side (right/left)	14 / 6	
Age (year)	27.0 (4.6)	27.3 (4.3)
Height (m)	1.66 (.09)	1.67 (.08)
Weight (kg)	62.9 (12.0)	64.5 (11.0)
Running period (month)	17.05 (4.00)	16.70 (3.75)

EG: experimental group, CG: control group.

The exclusion criteria were ankle range limitations (ankle dorsiflexion 30 degrees or less, plantar flexion 50 degrees or less), previous orthopedic surgery on the lower limb, use of foot orthoses, neurologic injuries or lesions, and other disorders such as osteoarthritis, rheumatoid arthritis, or osteoporosis in the feet in addition to achilles tendinopathy. Ample explanation was provided to the test subjects by the researcher regarding the purpose and the protocol of the study before the study was conducted, and all the subjects understood the explanation and agreed to participate. The project was approved by the University of Sahmyook Research Ethics Review Committee (SYUIRB2010-007, 27 February 2010), and the study protocol was conducted in strict accordance with the Declaration of Helsinki. Written informed consent was obtained from each subject.

Experimental procedure

The general features of the subjects, such as sex, age, weight, height, and body fat percentage, were recorded using bio-impedance body composition analyzer (Inbody 570, Biospace, Korea) before the test. For the EG, the clinical characteristics of achilles tendinopathy were also recorded, such as duration. Sixteen motion analysis markers (8 makers each side) were then attached to the subjects, who then were asked to walk in a manner suggested in a previous study, namely, repeating a distance of 13 m at their normal walking speed 5 times (Ryan et al., 2009).

Gait parameter analysis

For the gait analysis test in the EG and CG, three-dimensional movement analysis equipment was used, which comprised 9 infrared cameras, a signal control box, a computer, and the necessary software (VICON v8i motion analysis system; Vicon, Los Angeles, USA). The cameras received reflected infrared light from each marker, and location movement data were collected at 120 frames per second and an average accuracy of 0.85 mm.

Kinematic data were collected as primary data for body modeling by using Nexus 1.7 software (Vicon). From the collected data, the anatomic position was reanalyzed and used for bone structure modeling. Using the basic principles of physics, simple location data were converted to bone movement data with Polygon software (Oxford Metrics Ltd., Oxford, UK), whereby gait parameters such as cadence, single-limb support, double-limb support, limb index, step length, step time, step width, stride length, stride time, and walking speed were calculated and used for analysis.

To measure the joint moments of the EG and CG, a 60 cm × 90 cm-sized dual AMTI force platform (Advanced Mechanical Technology Inc., MA, USA) was used. After the current runs through the amplifier and is changed to a digital value by Nexus 1.7 software, it can be collected as primary data. Using basic principles of physics, hip, knee, and ankle moment data were then derived by Polygon software and used for analysis. The leg side used for comparisons between the EG and CG remains controversial. This study used the method described in a previous study by Choi et al., namely, use of the affected side in EG subjects and the dominant side in CG subjects (Choi et al., 2011).

Subjects were asked to walk a distance of 13 m on bare feet at their own walking speed and performed the test after a training period to fully understand the movements required. All subjects walked back and forth over the whole distance 5 times during the test, with a 1-minute rest between gait routes. All subjects who participated in the test wore black pants, which minimize the interference of clothing with joint movement and have excellent elasticity and a comfortable feeling on the skin. The location of the markers attached for three-dimensional movement analysis is shown in Figure 1.

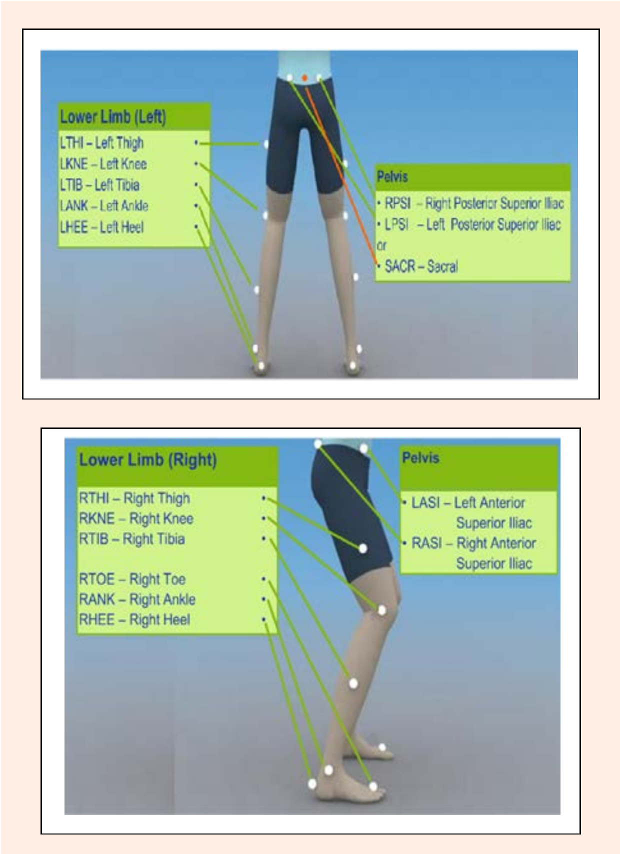

Figure 1. Location of marker for gait motion analysis.

The markers were plotted on the X-axis (coronal plane), Y-axis (sagittal plane), and Z-axis (transverse plane) on the basis of gait time and force platform data. The joint moment was calculated using the moment equation reported by Flanagan and Salem (2005), and the limb index was calculated by dividing the total limb support (single- + double-limb support) by the total limb support of the contralateral side of the lower body. All procedures were conducted directly by the researcher.

Statistical analysis

SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The mean and standard deviation were calculated using descriptive statistics to compare the general features, gait parameters, and hip, knee, and ankle moments between the EG and CG. Independent *t* tests were used to compare subject characteristics, gait parameters, and hip, knee, and ankle moments between the 2 groups,. The significance level (α) of all statistical tests was set below 0.05.

Results

There were no significant differences in subject characteristics between the EG and CG (Table 1). Gait parameter analysis showed significant differences between the EG and CG for double-limb support, step length, step width, stride length, stride time, and walking speed (Table 2). However, there were no significant differences between the EG and CG for cadence, single-limb support, limb index, and step time.

Table 2. Gait parameters differences between experimental group (EG, n = 20) and control group (CG, n = 20). Values are means (±Standard Deviation).

	EG	CG
Cadence (step·min^{-1})	110.7 (9.9)	114.7 (8.8)
Single limb support (%)	43.0 (3.5)	42.4 (3.0)
Double limb support (%)	22.7 (4.3)	20.4 (4.5)*
Limp index (score)	.99 (.03)	1.00 (.04)
Step length (m)	.58 (.07)	.64 (.08)**
Step time (second)	.54 (.05)	.53 (.05)
Step width (m)	.16 (.04)	.14 (.05)*
Stride length (m)	1.17 (.12)	1.28 (.14) **
Stride time (second)	1.09 (.10)	1.05 (.08) *
Walking speed (m·s^{-1})	1.09 (.18)	1.23 (.17) ***

* p < 0.05, ** p < 0.01, *** p < 0.001.

Table 3 and Figure 2 indicate the differences in moments between the EG and CG observed during the gait cycle. The hip joint moment showed a significant decrease for initial contact and increase for mid-stance, terminal stance, and pre-swing phases in the EG. A significant increase in knee joint moment was found for the initial contact phase, and a significant decrease was found for the pre-swing phase. In ankle joint moment, a significant increase was found for pre-swing and terminal swing phases.

Discussion

Spatial–temporal parameters

The results of this study show that, among the gait parameters assessed in runners with achilles tendinopathy, double-limb support, step length, step width, stride length, stride time, and walking speed showed significant differences compared with the CG. Walking speed has been identified as an indicator of functional activity and quality of life after diagnosis of the condition, and walking speed has been shown to affect activities of daily living (Jonsdottir et al., 2009). Moreover, walking speed is closely associated with other gait parameters. At a gait speed of 6 km per hour, which can generally be said to constitute fast walking, the increase in speed also increases cadence, step length, and stride length and produces a decrease in stance phase and double-limb support. This change has been shown not only in normal individuals but also in patients (Gaudreault et al., 2010; Stoquart et al., 2008).

According to gait studies conducted on ankle rheumatoid arthritis patients, a decrease in walking speed is known to comprise a strategic compensatory gait movement (Mejjad et al., 2004; Semple et al., 2007; Turner et al., 2008). In a study by Aronow and Hakim-Zargar (2007), it was reported that, in patients with ankle injury, slower walking speed is associated with shorter stride length, - observed in gait movement pattern. Further, injury, slower walking speed is associated with shorter stride length, - observed in gait movement pattern. Further, Laroche et al. (2007) showed that, compared with normal adults, patients with ankle injuries exhibit slower walking speeds, decreased stride length, and increased double-limb support percentage of gait cycle. Even in the present study, the EG showed a significant reduction in walking speed compared with the CG, and similar results have been observed for step length, stride length, and double-limb support in patients with other conditions. In previous studies, it was found that step width increases as gait time and step length decrease; this finding is similar to the results of the present study, which showed that the EG exhibited a decreased step length and stride length compared with the CG, but an increased step width.

Kinematics and dynamics

With respect to the moments of lower extremity joints in

Table 3. Joint moment (Nm·kg^{-1}) differences between experimental group (EG, n = 20) and control group (CG, n = 20). Values are means (±Standard Deviation).

	Hip		Knee		Ankle	
	EG	CG	EG	CG	EG	CG
Initial contact	.10 (.36)	.10 (.36)***	-.08 (.13)	-.08 (.20)**	-.04 (.06)	-.07 (.07)
Mid stance	.33 (.32)	-.01 (.24)**	-.01 (.33)	-.19 (.35)	.35 (.29)	.52 (.37)
Terminal swing	.21 (.70)	-.80 (.64)***	-.03 (.38)	-.01 (.29)	.74 (.60)	1.06 (.57)
Pre swing	-.10 (.25)	-.37 (.21)**	.01 (.08)	.10 (.09)**	.08 (.18)	-.01 (.07)*
Terminal swing	.10 (.13)	.07 (.10)	-.05 (.08)	-.01 (.06)	.00 (.01)	-.03 (.02)***

* p < 0.05, ** p < 0.01, *** p < 0.001.

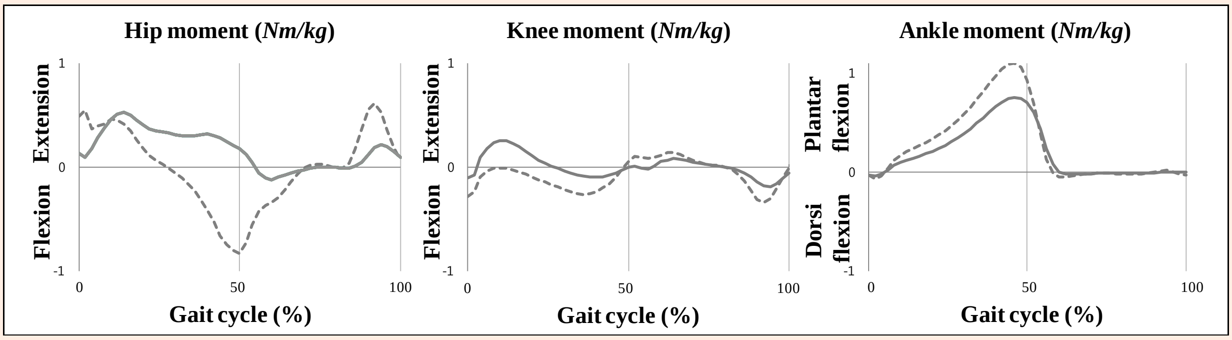

Figure 2. Lower limb dynamics during the gait cycle. The results are expressed in percentage of the gait cycle. The curves correspond to the mean value in the experimental group (EG, solid gray line) and the control group (CG, dashed gray line). The affected side in runners with achilles tendinopathy was measured in EG., and dominant side was measured in CG.

the sagittal plane under normal gait conditions, the hip generates trunk control, stabilization, and moment for hip extension during the initial contact, whereas in mid-stance, the hip generates flexion moment to reduce hip extension. This flexion moment is generated as a result of the passive force on the anterior capsule of the hip and hip flexor muscle activation. Thereafter, in the swing phase, extension moment is generated for the decrease in hip flexion movement. When the knee moment is observed in the sagittal plane during the initial contact, it can be seen to absorb shock and provide adequate knee array through the flexion moment, which is immediately followed by the occurrence of knee extension that is maintained until mid-stance and is then converted again to flexion moment during the terminal swing phase. The ankle shows a plantar flexion moment until mid-stance, which is decreased thereafter and consistently maintained during the swing phase (Gaudreault et al., 2010). This aspect of normal lower limb joint moment conforms to the average moment changes that occurred during the gait cycle of CG subjects in this study.

The maximal plantar flexion moment of the normal ankle tends to increase in proportion to the increase in walking speed (Stoquart et al., 2008). On the contrary, in patients whose walking speed is reduced because of pain and musculoskeletal problems, the maximal plantar flexion moments decrease (Lelas et al., 2003; Scott and Winter, 1990). The ankle moments recorded in our study show that the plantar flexion moment of EG subjects during the pre-swing phase was decreased compared with CG subjects, which corresponds with the observation that walking speed is decreased in achilles tendinopathy patients. It is believed that the structural changes caused by the damage to the achilles tendon affect plantar flexion (Wagner et al., 2004).

In our study, the hip moment showed significant differences for initial contact, mid-stance, terminal stance, and pre-swing phases. The extension moment, which should normally occur during the initial contact, and the flexion moment, which should appear from mid-stance, were found to be decreased in the EG. Even in the knees, the flexion moment, which occurs during the initial contact and is needed for initial shock absorbance, and the pre-swing extension moment were found to be decreased in the EG compared with the CG. This finding indicates that the turning force that is generated in the hip and knee is decreased in EG subjects. Novak and Brouwer (2011) examined the lower body moments of elderly people, in whom walking speed and stride length are relatively decreased compared with adults in their 20s, and found that the maximal moments in the hip, knee, and ankle during the gait cycle were decreased compared with adults in their 20s. Similar to this previous study, the hip and knee moments in our study were found to be lower during maximal moment generation in the EG compared with the CG. Furthermore, Lewis and Ferris (2008) showed that the change in ankle moment during the stance phase affects the hip moment, and McCrory et al. (1999) found that achilles tendinopathy patients experience kinetic changes in the lower extremities because of the decrease in plantar flexion range of motion in the stance phase, and that the decrease in ankle moment, which is affected by the decrease in walking speed, appears to have an indirect effect on the formation of the hip moment. When looking at existing studies on the co-relationship between lower extremity joints, it can be seen that, in the case of anterior cruciate ligament patients, the knee moment correlates with other lower body joints, resulting in changes in hip and ankle moments during gait (Shimokochi et al., 2009).

Such changes in lower extremity joint moments interrupt the formation of energy-efficient moments of each joint and can cause various changes in these joints (Bulgheroni et al., 2007). Further, a reduction in stance phase moment reduces the overall range of motion in the lower extremities, which may result in claudication (Jonsdottir et al., 2009).

As indicated above, changes in gait parameters and hip, knee, and ankle moments occur in runners with achilles tendinopathy. Therefore, the clinical features of these gait changes should be understood for optimal treatment of achilles tendinopathy, and further research on this topic is required.

Conclusion

From our findings, it is evident that a reduction in gait parameters, namely, step length, stride length, and walking speed, and an increase in double-limb support occurs in runners with achilles tendinopathy. Further, it was found that a reduction in the hip extension moment occurs during the initial contact, as well as a reduction in the knee flexion moment from the mid-stance to pre-swing phases, a continuous decrease in the knee flexion moment from the early stance phase, and a reduction in the extension moment during the terminal stance phase. It was also observed that a reduction in the ankle plantar flexion moment occurs from the mid-stance phase and that a reduction in the dorsiflexion moment occurs during the terminal swing phase. Therefore, for the clinical treatment of achilles tendinopathy, these gait change features should be better defined, which warrants further studies on this topic.

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Key points

- A reduction in gait parameters, namely, step length, stride length, and walking speed, and an increase in double-limb support occurs in runners with achilles tendinopathy.
- A reduction in the hip extension moment occurs during the initial contact, as well as a reduction in the knee flexion moment from the mid-stance to pre-swing phases, a continuous decrease in the knee flexion moment from the early stance phase, and a reduction in the extension moment during the terminal stance phase.
- A reduction in the ankle plantar flexion moment occurs from the mid-stance phase and that a reduction in the dorsiflexion moment occurs during the terminal swing phase.

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