

Research article

Comparison of pathway and center of gravity of the calcaneus on non-involved and involved sides according to eccentric and concentric strengthening in patients with Achilles tendinopathy

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Abstract

This study compares the changes in pathway and center of gravity (COG) on the calcaneus of non-involved and involved sides according to eccentric and concentric strengthening in patients with unilateral Achilles tendinopathy. The goal was to define the biomechanical changes according to eccentric strengthening for the development of clinical guidelines. Eighteen patients with Achilles tendinopathy were recruited at the K Rehabilitation Hospital in Seoul. The subjects were instructed to perform 5 sessions of concentric strengthening. The calcaneal pathway was measured using a three-dimensional (3D) motion analyzer, and COG was measured by a force plate. Subsequently, eccentric strengthening was implemented, and identical variables were measured. Concentric and eccentric strengthening was carried out on both the involved and non-involved sides. There was no significant difference in the calcaneal pathway in patients with Achilles tendinopathy during concentric and eccentric strengthening. However, during eccentric strengthening, the calcaneal pathway significantly increased on the involved side compared to the non-involved side for all variables excluding the z-axis. COG significantly decreased on the involved side when compared to the non-involved side in patients with Achilles tendinopathy during eccentric and concentric strengthening. During concentric strengthening, all variables of the COG significantly increased on the involved side compared to the non-involved side. Compared with eccentric strengthening, concentric strengthening decreased the stability of ankle joints and increased the movement distance of the calcaneus in patients with Achilles tendinopathy. Furthermore, eccentric strengthening was verified to be an effective exercise method for prevention of Achilles tendinopathy through the reduction of forward and backward path length of foot pressure. The regular application of eccentric strengthening was found to be effective in the secondary prevention of Achilles tendinopathy in a clinical setting.

Key words: Achilles tendinopathy, concentric, eccentric, motion analyzer, center of gravity, foot pressure.

Introduction

Eccentric strengthening relies on the contraction generated with increased muscle length during exercise. Although the mechanism underlying treatment of Achilles tendinopathy through eccentric strengthening remains unclear, the most reasonable hypothesis is that the stimulation generated by a specific increase is accompanied by strengthening to achieve visco-elastic change within the organ (Allison and Purdam, 2009). Active eccentric strengthening adjusts the threshold level for activity of the peripheral and central nervous systems, and creates an

optimal increase-decrease cycle to synchronize the short-term and long-term accommodation reflexes of the exercise unit (Avela and Komi, 1998; Nicol et al., 2006). Furthermore, the eccentric load is moved to a position in which myotomes within the muscle can produce maximum contraction. This, in turn, leads to the mutual connection of a range that can display both optimal passive and active function (Brockett et al., 2004; Proske et al., 2004).

Previous studies have reported that use of eccentric strengthening in patients with Achilles tendinopathy is effective in reducing pain (Knobloch et al., 2009; Rompe et al., 2008). Silbernagel et al. (2001) reported that compared with concentric strengthening, eccentric strengthening produces a significant increase in both complete recovery of damage and patient satisfaction, as well as a decrease in pain during activity. Rompe et al. (2007) used pain threshold equipment to compare an eccentric strengthening group with an external shock therapy group and a control group; they reported that eccentric strengthening produced greater reduction in pain as well as an increase in functional standard and pain threshold value. Although the pain reduction effect of eccentric strengthening is used clinically in rehabilitation settings, the mechanism underlying the efficacy of the approach remains unclear. Eccentric load can deliver greater strength to the tendon than does a concentric load, and can eventually increase the ratio of stimulation required for tendon reconstruction (Fyfe and Stanish, 1992; Stanish et al., 1986). Furthermore, although long-term eccentric strengthening gradually normalizes damaged tendon structure, no clear evidence for any relevant blood supply mechanism has been reported (Ohberg et al., 2004).

Recent studies have attempted to uncover the mechanism underlying the effects of eccentric strengthening. Piitulainen et al. (2010) stated that compared with concentric strengthening, eccentric strengthening is more efficient in producing contraction as well as achieving a higher conduction speed in muscle fibers. In a contrasting study, Rees et al. (2008) used three-dimensional (3D) motion analysis equipment and electromyograms in an initial study on the dynamic efficiency of eccentric strengthening and concentric strengthening of the Achilles tendon. Although a significant difference was not evident in the maximum tendon contraction ability and tendon length during motion, eccentric strengthening was found to generate a higher frequency of force vibration in the

Table 1. Subject characteristics. Data are means (\pm SD).

Subjects n	Gender (M/F)	Injured side (R/L)	Age (years)	Height (m)	Weight (kg)	Leg length (cm)	Foot size (mm)
18	9/9	12/6	26.22 (4.14)	1.66 (.09)	63.06 (12.08)	78.15 (6.88)	256.13 (16.99)

tendon in comparison with that elicited with concentric strengthening. However, this investigation was performed on control subjects, and no study has directly treated patients with Achilles tendinopathy. Furthermore, to analyze the mechanism of eccentric strengthening more thoroughly, it is necessary to compare the differences in maximum muscle contraction and position variables during both eccentric and concentric strengthening. This analysis should also encompass comparison of tendinopathic and non-tendinopathic regions of the Achilles tendon and a comparison of the affected and non-affected sides.

In Achilles tendonitis, calcaneal pathway may change because the Achilles tendon has an insertion into the calcaneus itself. Examination of the calcaneal pathway in patients with Achilles tendinopathy would therefore be of some importance, and should any abnormalities be noted, it would also be imperative to ascertain the direction in which the bone has moved. An increased pathway of the calcaneus in patients with Achilles tendinopathy signifies instability, functional inefficacy, and a marked limitation of function. This study compared the changes in maximal muscle contraction, calcaneal pathway, and center of gravity (COG) of involved and non-involved sides with regard to eccentric and concentric strengthening in patients with unilateral Achilles tendinopathy. Thus, this study aimed to define biomechanical changes resulting from eccentric strengthening methods and assess the superior efficacy of eccentric strengthening in order to formulate clinical guidelines.

Methods

Subjects

Eighteen patients with chronic Achilles tendinopathy were recruited from the research center of the K Rehabilitation Hospital located in Seoul. The following types of patients were selected: patients diagnosed with Achilles tendinopathy due to the discovery of unilateral structural abnormality on ultrasonography, patients who had been first diagnosed with Achilles tendinopathy at least 6 months previously and patients who were able to receive outpatient follow-up inspection and could walk independently without assistive devices. Patients excluded from the trial were those with severe restrictions in the range of movement in the ankles; those who had previously undergone orthopedic surgery in a lower extremity; those currently using a foot orthotic; those with other concomitant disease in the feet, such as osteoarthritis, rheumatoid arthritis, and osteoporosis; and those with other neurological damage or lesions in addition to the selected disease. Before investigation, the researcher provided a thorough explanation to the subjects regarding experimental purpose and procedure. All subjects understood the relevant content and agreed to participate in the study. The general characteristics of the subjects are shown in Table 1.

Procedure

As a preliminary inspection, the general characteristics of subjects (gender, age, weight, height, and body fat percentage) were investigated along with the clinical characteristics (period of disease). A motion analysis marker was attached to the involved and non-involved lower body parts of all subjects. Bare-footed subjects climbed the force plate to perform 5 sessions of 8-second concentric strengthening of the Achilles tendon, moving from maximum dorsiflexion to maximum plantar flexion according to the method presented by Rees et al. (2008). Variables for the calcaneal pathway and COG were calculated. After taking a 1-minute break, the subjects performed 5 sessions of 8-second eccentric strengthening of the Achilles tendon, moving from maximum plantar flexion to maximum dorsiflexion; these sessions were used to calculate identical variables. The floor behind the force plate was removed to prevent the calcaneus and heels from touching the surface during dorsiflexion. The researcher substituted the collected data into the formula for analysis (Figure 1).

Measurements

3D motion analysis

The calcaneal pathway of the patients with Achilles tendinopathy was measured using 3D motion analysis equipment. The 3D analysis equipment is composed of 9 infrared cameras, a signal control box, computer, and software. A VICON v8i motion analysis system (Vicon, Los Angeles, CA, USA) was used for the camera and signal control box. Location movement data was filmed at 120 frames per second at an average accuracy of 0.85 mm. The infrared light reflected from each marker was collected by the camera. Nexus 1.7 software (Vicon) was used for kinematic data to collect primary data for whole-body modeling. Anatomical posture was re-analyzed based on the collected data to compose the skeletal structure model. Basic principles of physics were used to convert simple location data to skeletal movement using Polygon software (Oxford Metrics, Oxford, UK). The pathway of the calcaneus was calculated in the X-axis (coronal plane), Y-axis (sagittal plane), and Z-axis (horizontal plane). All subjects who participated in the experiment wore black trousers with high elasticity and skin contact to minimize the interference of clothing and reflection of infrared light during motion.

Measurement of foot pressure

To calculate joint moment in subjects with Achilles tendinopathy, a dual AMTI force platform (Advanced Mechanical Technology, Watertown, MA, USA) with dimensions of 60 cm \times 90 cm was used for inspection. A strain gauge was installed in 4 parts of the force plate platform and attached to the load cell. In the experimental design, changes in the length of the load cell produce alterations in the diameter of lines within the gauge; this transforms the resistance value of the electric current

$$\begin{aligned}
 \text{Coronal plane pathway} &= \sum_{i=1}^n \sqrt{(x_n - x_i)^2} \\
 \text{Sagittal plane pathway} &= \sum_{i=1}^n \sqrt{(y_n - y_i)^2} \\
 \text{Transverse plane pathway} &= \sum_{i=1}^n \sqrt{(z_n - z_i)^2} \\
 \text{Total pathway} &= \sum_{i=1}^n \sqrt{(x_n - x_i)^2 + (y_n - y_i)^2 + (z_n - z_i)^2}
 \end{aligned}$$

Figure 1. Calculate formula in pathway of calcaneus and COG during eccentric and concentric strengthening.

flowing in the line. This electric current passes through the amplifier, is converted into a digital value in the Nexus 1.7 software through the AD transformer, and is then collected as primary data. Subsequently, basic principles of physics were used to extract data using the Polygon software to generate the results. The rear floor of the force plate was removed to prevent the subject’s heels from touching the surface. The subjects performed eccentric and concentric strengthening while standing on the force plate. The forward and backward, internal and external, and total path length of COG was calculated according to exercise.

Statistical analysis

We calculated the data using the mathematical formula shown in Figure 1 and obtained the calcaneal pathway of patients with Achilles tendinopathy. SPSS version 12.0 (SPSS, Chicago, IL, USA) was used for the statistical analyses. Descriptive statistics were used to calculate the mean and standard deviation in order to compare the general characteristics of the patients with Achilles tendinopathy with the calcaneal pathway of involved and non-involved sides according to eccentric and concentric strengthening, as well as variables for COG. A paired t-test was used to quantify the difference between the involved and non-involved parts, while two-way repeated ANOVA was used to compare the difference in eccentric and concentric strengthening in the involved and non-involved sides. The significance standard of all statistics was set at <0.05.

Results

Difference in pathway of the calcaneus during eccen-

tric and concentric strengthening

The X-axis, Y-axis, and total pathway of the involved side significantly increased in the involved side compared to the non-involved side during eccentric strengthening, excluding the Z-axis (p < .05). In addition to this, compared to the non-involved side, the involved side showed a significant increase in all variables during concentric strengthening (p < .05). However, on comparison of eccentric and concentric strengthening, there were no significant differences in the X-, Y-, and Z-axes or in the total pathway of the calcaneus. Compared to the non-involved side, the involved side showed a significant increase in all variables. There were no significant differences in the interaction effect of eccentric or concentric strengthening and involved or non-involved side (Table 2).

Difference in COG during eccentric and concentric strengthening

There was no significant difference between the involved and non-involved sides in terms of anterior and posterior, medial and lateral, and total path length of the COG during eccentric strengthening. All variables of the involved side significantly increased when compared with those of the non-involved side during concentric strengthening (p < 0.05). There was a significant difference between eccentric and concentric strengthening in terms of anterior and posterior, medial and lateral, and total path length of the COG (p < 0.05). A significant difference was also found between the involved side and the non-involved side for all variables. Furthermore, significant differences were found in the interaction effect between eccentric and concentric strengthening and between the involved and non-involved sides (Table 3).

Table 2. Difference in pathway of calcaneus during eccentric and concentric strengthening. Data are means (±SD).

Measures	Injured Side	Eccentric strengthening	Concentric strengthening	Strengthening (F)	Injured Side (F)	Strengthening×Side (F)
X axis(mm)	Involved side	283.6 (169.3) #	242.3 (144.7) #	2.372	19.364 *	.421
	Non-involved side	105.2 (60.4)	83.3 (28.6)			
Y axis(mm)	Involved side	507.8 (344.0) #	405.4 (323.2) #	2.540	19.867 *	1.494
	Non-involved side	121.5 (142.9)	76.0 (35.1)			
Z axis(mm)	Involved side	325.5 (155.0)	344.6 (144.5) ‡	.000	9.962 †	1.264
	Non-involved side	243.6 (83.8)	223.5 (35.0)			
Total(mm)	Involved side	798.9 (436.3) #	677.8 (392.1) #	2.254	18.180 †	1.111
	Non-involved side	336.7 (198.1)	276.2 (56.9)			

* p < 0.001, † p < 0.01: two way repeated ANOVA for involved side and non-involved side differences in Eccentric and Concentric strengthening. # p < 0.001 ‡ p < 0.01: paired t-test for involved side and non-involved side differences.

Table 3. Difference in COG during eccentric and concentric strengthening. Data are means (\pm SD).

Measures	Injured Side	Eccentric strengthening	Concentric strengthening	Strengthening (F)	Injured Side (F)	Strengthening \times Side (F)
APP (mm)	Involved side	8.80 (1.90)	12.44 (2.41) #	28.586 *	10.224 †	8.191 \$
	Non-involved side	8.87 (1.68)	9.40 (1.81)			
LMP (mm)	Involved side	5.33 (1.40)	7.33 (2.16) ‡	16.525 †	5.986 \$	9.232 †
	Non-involved side	5.46 (.92)	5.46 (1.15)			
Total (mm)	Involved side	11.54 (2.36)	15.96 (2.84) #	30.777 *	13.506 †	10.198 †
	Non-involved side	11.40 (1.89)	12.05 (2.07)			

APP: anterior and posterior pathway. LMP: lateral and medial pathway. * $p < 0.001$, † $p < 0.01$, \$ $p < 0.05$: two way repeated ANOVA for involved side and non-involved side differences in Eccentric and Concentric strengthening. # $p < 0.001$ ‡ $p < 0.01$: paired t-test for involved side and non-involved side differences.

Discussion

This study investigated changes in the pathway of the calcaneus and COG of the involved and non-involved sides during eccentric and concentric strengthening in patients with Achilles tendinopathy. Rees et al. (2008) conducted an initial study on the dynamic efficiency of eccentric and concentric strengthening of the Achilles tendon. They concluded that although there was significant difference in the maximum muscle contraction and length of tendon between the exercise techniques, a higher frequency of force vibration was generated in the tendon during eccentric strengthening than during concentric strengthening. However, as the subjects in the 2008 study were 7 patients unaffected by Achilles tendinopathy, it is somewhat unreasonable to apply these results to patients with Achilles tendinopathy. Furthermore, there was no evaluation of muscles with regard to motion; therefore, the present study investigated the mechanical variables of the involved and non-involved sides in patients with Achilles tendinopathy by using an identical method.

Although there were no significant differences in the calcaneal pathway between the involved and non-involved sides according to whether eccentric or concentric strengthening was used, the pathway of the involved side was significantly increased compared with that observed on the non-involved side. The decrease in the calcaneal pathway observed during identical functional motions signified the manifestation of accurate, steady motor skills. This is due to an increase in proprioception and can be expressed as an increase in joint stability. Achilles tendinopathy patients present excessive eversion and dorsiflexion of subtalar joints and also display excessive eversion on walking. The continuation of such a gait can aggravate damage of the intermediate fiber of the Achilles tendon (Clement and Taunton, 1984). In this regard, factors such as a change in position of the gastrocnemius muscle according to ankle movements are contributing factors that can trigger Achilles tendinopathy (Kader et al., 2002; Maffulli et al., 2003; Paavola et al., 2002; Wilder and Sethi, 2004). The changes in calcaneus position in Achilles tendinopathy are regarded as being parallel to the increase in pathway of the involved side in comparison to the non-involved side. Furthermore, the results of this study verify that the location of the calcaneus does not change according to exercise.

Compared with concentric strengthening, eccentric

strengthening of the involved side has been found to decrease the path length of the COG. The reduction of path length also signifies the steady movement of the COG to an essential minimum distance in identical functional motion. Goryachev et al. (2011) stated that the therapeutic treatment of the ankle triggers changes in the path length of foot pressure and that such changes affect electromyogram patterns during activity. Such a decrease in the path length of the COG is achieved through repositioning of muscular activities during eccentric strengthening, thus verifying the effectiveness of the approach in treating Achilles tendinopathy pain. Furthermore, Van Ginckel et al. (2009) reported significant reduction in variables that act as triggering factors for Achilles tendinopathy according to the decrease in forward and backward movement of COG and lateral deviation. In this regard, eccentric strengthening is regarded as a very useful method for rehabilitating patients with Achilles tendinopathy because compared with concentric strengthening, eccentric strengthening effectively reduces the forward, backward, and total path length of the COG. Concentric strengthening also produces increased forward, backward, and total path length of the COG for the involved side compared with the non-involved side. Thus, concentric strengthening showed lower efficiency than that of eccentric strengthening in effective management of factors that trigger Achilles tendinopathy.

Eccentric strengthening was found to be an effective exercise in preventing Achilles tendinopathy through reduction of forward and backward path length of foot pressure. Thus, regular eccentric strengthening can be useful for the secondary prevention of Achilles tendinopathy in the clinical setting.

Conclusion

This study attempted to compare changes in the pathway of the calcaneus and the COG of the involved and non-involved sides according to the use of eccentric or concentric strengthening techniques in patients with Achilles tendinopathy. The pathway of the calcaneus in the involved side significantly increased for all variables (excluding the Z-axis) during eccentric strengthening ($p < 0.05$). The path length of the COG in the involved part significantly decreased in patients with Achilles tendinopathy during both eccentric and concentric strengthening ($p < 0.05$), while all path lengths in the involved side significantly increased during concentric strengthening (p

< 0.05). These results verify the theory that Achilles tendinopathy reduces the stability of the foot when pressure is applied, increasing the movement of the calcaneus. Furthermore, eccentric strengthening is confirmed as an effective method for prevention of Achilles tendinopathy through reduction of forward and backward path length of foot pressure. Thus, regular application of eccentric strengthening is useful in the secondary prevention of Achilles tendinopathy in a clinical setting.

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Key points

- Compared with eccentric strengthening, concentric strengthening decreased the stability of ankle joints, increasing movement of the calcaneus in patients with Achilles tendinopathy.
- Eccentric strengthening was shown to be an effective exercise method for preventing Achilles tendinopathy through the reduction of forward and backward path length of foot pressure.
- It was verified that regular application of eccentric strengthening is effective in secondary prevention of Achilles tendinopathy in the clinical setting.

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