

Effect of treadmill walking with ankle stretching orthosis on ankle flexibility and gait

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Abstract. [Purpose] The purpose of this study was to evaluate the kinematics of the ankle in the lunge to establish effectiveness of an ankle stretching orthosis (ASO) on the ankle dorsiflexion range of motion (ROM) of individuals with limited dorsiflexion ROM. [Subjects and Methods] Forty ankles with decreased dorsiflexion ROM of 20 participants were evaluated in this study. After wearing the ASO, participants walked on a treadmill for 15 minutes. Participants walked on the treadmill at a self-selected comfortable speed. Ankle dorsiflexion ROM, maximum dorsiflexion ROM before heel-off, and time to heel-off during the stance phase of gait were measured before and after 15 minutes of treadmill walking with the ASO. The differences in all variables between before and after treadmill walking with ASO were analyzed using the paired t-test. [Results] Ankle active and passive ROM, and dorsiflexion ROM during lunge increased significantly after treadmill walking with ASO. Treadmill walking with the ASO significantly increased the angle of maximal dorsiflexion before heel-off and time to heel-off during the stance phase. [Conclusion] The results of this study show that treadmill walking with the ASO effectively improved ankle flexibility and restored the normal gait pattern of the ankle joint by increasing dorsiflexion ROM, maximal angle of dorsiflexion, and time to heel-off in the stance phase.

Keywords: Ankle stretching orthosis, Ankle dorsiflexion range of motion, Gait

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INTRODUCTION

Normal flexibility of the ankle joint is necessary for functional activities such as gait¹⁾. Limited ankle joint dorsiflexion range of motion (ROM) can cause altered foot position and compensatory movement leading to musculoskeletal pain and lower extremity overuse injuries, as well as an abnormal gait pattern²⁾. For normal walking, adequate dorsiflexion ROM is necessary to contribute to the distribution of the body weight during the stance phase of walking³⁾. Adequate dorsiflexion motion at the talocrural joint is necessary for normal functional activities of ankle joint, such as walking, running, jumping and many other weight-bearing activities. A minimum of 10° of dorsiflexion is required for walking, and 30° is needed for running⁴⁾. Jordan et al.⁵⁾ reported that the ankle joint dorsiflexes 4° to 10° beyond neutral during the stance phase of walking, and maximal dorsiflexion occurs just before heel-off. Insufficient talocrural dorsiflexion increases risk factors of gait impairments during walking

and running⁴⁾. Limited ankle dorsiflexion ROM during knee extension could result in compensatory changes during walking, such as earlier time to heel off, increased pronation, and midtarsal joint dorsiflexion⁶⁾. A previous study showed that participants with limited ankle dorsiflexion ROM showed earlier heel-off than individuals with normal ankle dorsiflexion⁷⁾. Early heel-off may increase the time of weight-bearing on the forefoot during the stance phase of gait, resulting in ankle and forefoot injuries⁸⁾. Repetitive abnormal loading on the forefoot may cause various injuries, such as plantar fasciitis, achilles tendinitis, and ankle sprain.

Insufficient length of the gastrocnemius muscle, soleus muscle, and the achilles tendon and abnormal joint structures of the talocrural joint contribute to limited ankle dorsiflexion ROM⁴⁾. Tightness of the calf muscles could impede the progression of the tibia on the talus, which favors the occurrence of an excessive compensatory pronation of the subtalar joint during gait^{9, 10)}. Various techniques have been used for increasing ankle dorsiflexion ROM to prevent biomechanical change during gait and overuse injuries in rehabilitation and sports. Ankle dorsiflexion ROM can be increased via a variety of training and clinical techniques such as muscle stretching, mobilization with movement (MWM), and talus-stabilizing taping (TST).

A new Ankle Stretching Orthosis (ASO) was designed to stretch the ankle joint during walking. The ASO is a modification of the University of California Berkley Laboratory

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(UCBL) foot orthosis and strap. The strap divides the talus strap and the midfoot strap. The talus strap can be applied to the talus in the anterior to posterior with superior to inferior direction in a diagonal manner⁴). The talus strap can also be used to help provide stability to the talus by pulling the strap placed on the talus during closed chain activities requiring tibial advancement on the foot⁴). The midfoot strap provides stability for orthosis.

The purpose of this study was to evaluate the effectiveness of the ASO at increasing the dorsiflexion ROM of individuals with limited dorsiflexion ROM. We hypothesized that passive and active ankle dorsiflexion ROM, lunge angle, maximum dorsiflexion ROM before heel-off, and time to heel-off during the stance phase of the gait would increase after treadmill walking with the ASO.

SUBJECTS AND METHODS

All single-blind design measurements were performed by a trained physical therapist. Two examiners measured ankle dorsiflexion (DF) ROM. Active DFROM and passive DFROM at 0 and 90° knee flexion were measured. The first examiner stabilized the pelvis and lower extremities to avoid compensation by other joints while active DFROM was measured. For passive DFROM measurements, a hand-held dynamometer (JTECH Medical, Salt Lake City, UT, USA) was used to monitor constant pressure while measuring passive dorsiflexion ROM. The hand-held dynamometer was placed at a point on the forefoot plantar surface 8 cm from the lateral malleolus while a constant moment of force (torque) was applied. Torque, which was monitored by the hand-held dynamometer, was applied at 111 N of force perpendicular to the plantar surface of the forefoot¹¹). The second examiner checked the neutral position and measured the angle of the subtalar joint during all ankle DFROM measurements. The axis of the goniometer were located at the lateral malleolus while the stationary arm and moving arm were placed at the fibular head and parallel to the lateral side of the central fifth metatarsal bone during the measurements. For measuring dorsiflexion ROM, a 14-inch stainless steel goniometer (Jamar, Jackson, MI, USA) was used. Active DFROM and passive DFROM at 0 and 90° knee flexion were measured. A five-minute rest was given after every measurement to minimize learning and carry over effects. All ankle DFROM measurements were performed three times, and the goniometer was repositioned every time. The average values were used in the data analysis.

To measure lunge angle, an inclinometer was positioned at a point 15 cm below the center of tibial tuberosity (Baseline Inclinometer, Irvington, New York). A line was drawn on the ground to keep the alignment between the heel and second toe of the subject during lunge¹²).

A VICON motion analysis system with eight VICON MX-T10 cameras (Vicon Motion Systems Ltd., Oxford, UK) was used to capture ankle kinematic data during gait. Nineteen markers (with a diameter of 10 mm) were attached to the major body parts using Helen Hayes Marker set¹³). During the static trial, reflective markers were bilaterally attached to the anterior superior iliac spine, anterior midthigh, anterior midshank, lateral femoral epicondyle, medial

femoral epicondyle, lateral malleolus, medial malleolus, second metatarsal head, and calcaneus. For the dynamic trial, the medial femoral epicondyle and medial malleolus markers were removed before the participants walked on a walkway in bare feet at a comfortable speed selected by themselves in the motion analysis laboratory. A total of five trials were performed and the average of three of them was used in the analysis. Maximum ankle DF before heel-off and time to heel-off the stance phase were calculated using Nexus software, version 1.7 (Vicon Motion Systems Ltd., Oxford, UK). In this study, the duration between heel-strike and toe-off was expressed as a percentage of the duration of the stance phase^{2, 14}).

Participants walked on treadmill with the ASO after baseline measurements. The ASO was attached while subjects sat on a chair with their knees flexed 90 degrees. The talus strap and midfoot strap were pulled and fastened in pain-free positions. The heel counterpart of the orthosis was cut to decrease friction on the heel area during walking. The subjects wore running shoes to minimize backward foot slides. A soft pad was placed over the posterior lateral part of the ASO to decrease skin friction with the orthosis. The medial and lateral walls of the ASO were cut away about 2.5 cm below the medial and lateral malleolus to prevent friction at the malleolus. The forefoot bottom of the ASO was cut away at the metatarsal head to allow for a natural rollover motion at the metatarsophalangeal joint when walking. After attaching the ASO orthosis to the foot tightly, and running shoes, 15 minutes of treadmill walking was performed at a self-selected comfortable speed. After fifteen minutes of walking on the treadmill with the ASO, all the variables were measured again after a 10-minute rest.

To assess the statistical significance of changes in each parameter after walking with the ASO, the paired t-test was used. A p value <0.05 was considered to indicate statistical significance. The statistical package for the Social Sciences for Windows version 18.0 (SPSS, Inc., Chicago, IL, USA) was used for statistical analysis.

RESULTS

The changes in active and passive dorsiflexion ROM, and the tibia angle during lunge after treadmill walking with ASO are shown in Table 1. Both active and passive dorsiflexion ROMs significantly increased after treadmill walking with the ASO ($p < 0.05$). The lunge angle demonstrated a statistically significant increase ($p < 0.05$).

The degree of maximal ankle dorsiflexion before heel-off demonstrated a statistically significant increase (Table 2) ($p < 0.05$). The time to heel-off during the stance phase of the gait also significantly increased after treadmill walking with the ASO (Table 2) ($p < 0.05$).

DISCUSSION

Limited ankle dorsiflexion ROM may increase stress at the plantar site and is associated with lower extremity overuse injuries due to subtalar joint pronation and early heel-off in compensatory foot motion during gait. Because of the importance of ankle dorsiflexion ROM, many clini-

Table 1. Comparison of the ankle dorsiflexion ROM before and after wearing the orthosis (Units: °)

Variables	Mean \pm SD (°)		Mean difference (95% CI)
	Before orthosis	After orthosis	
DF PROM with knee flexion 0°	6.04 \pm 3.46	13.77 \pm 3.31	-7.73* (-8.21 to -6.64)
DF PROM with knee flexion 90°	20.05 \pm 4.31	27.92 \pm 5.34	-7.87* (-9.53 to -6.20)
DF AROM with knee flexion 0°	8.32 \pm 5.79	13.87 \pm 4.25	-5.54* (-6.79 to -4.30)
DF AROM with knee flexion 90°	18.25 \pm 6.56	23.95 \pm 7.08	-5.70* (-7.44 to -3.96)
Lunge angle°	42.03 \pm 4.18	46.43 \pm 4.71	-4.41* (-5.82 to -2.99)

*, $p < 0.05$ (paired t-test). DF: dorsiflexion; PROM: passive range of motion; AROM: active range of motion; CI: confidence interval

Table 2. Comparison of the ankle dorsiflexion ROM before heel-off and time to heel-off during the stance phase of gait before and after wearing the orthosis

Variables	Mean \pm SD (°)		Mean difference (95% CI)
	Before orthosis	After orthosis	
Maximal ankle DF ROM before heel-off (°)	7.96 \pm 4.56	13.00 \pm 5.65	-5.04* (-6.73 to -3.35)
Time to heel-off (%)	33.22 \pm 4.26	35.72 \pm 4.11	-2.50* (-3.31 to -1.68)

*, $p < 0.05$ (paired t-test). DF: dorsiflexion; ROM: range of motion; CI: confidence interval

cians make great efforts to find an intervention which increases ankle dorsiflexion ROM. This study investigated the effects of treadmill walking with an ASO on ankle flexibility and gait pattern by measuring passive and active ankle dorsiflexion ROM, the angle of maximal dorsiflexion ROM, and time to heel-off during gait of individuals with limited ankle dorsiflexion.

Treadmill walking with the ASO increased passive and active dorsiflexion ROM of the participants. There were also changes in the angle of maximal ankle dorsiflexion and time to heel-off during the stance phase of gait. These findings suggest that treadmill walking with the ASO improves ankle flexibility and normalizes the gait pattern. Loss of ROM, particularly dorsiflexion, results in significant gait dysfunction and overuse injury. Pope et al.¹⁵⁾ demonstrated that decreased dorsiflexion ROM is associated with pain and an increased risk of ankle injury. One of the most common methods of treatment for limited ankle dorsiflexion is the use of external support, such as bracing and taping. External ankle support using taping or a brace is effective in rehabilitation and at preventing ankle injuries, such as sprain^{16, 17)}. The present results show that treadmill walking with the ASO increased passive, active, and weight-bearing dorsiflexion ROM. These results are in agreement with the study by Yoon et al.¹⁸⁾, who found that 5 minutes walking with talus gliding taping increased ankle dorsiflexion ROM. In addition to this, Kang et al.¹⁹⁾ reported that walking with talus taping significantly increased the ankle dorsiflexion ROM of individuals with limited ankle dorsiflexion. The

TST technique is widely used as an intervention in physiotherapy treatment²⁰⁾. Ankle taping applied from the anterior-superior to the posterior-inferior direction can assist the functional activities, such as walking and lunge, of subjects with limited dorsiflexion ROM¹⁹⁾. However, the MWM and TST techniques have limitations, because only a therapist in the physical therapy room can perform the taping, since independently wrapping a taping around the talus is difficult to perform¹⁹⁾. Treadmill walking with the ASO may elicit a similar effect on the ankle joint because the talus strap applied anterior-superiorly and posterior-inferiorly over the talus may help stabilize the talus during the gait. A previous study showed that passive DFROM with 0 degree knee flexion was 7.71 \pm 1.80 degree before walking with taping and 11.96 \pm 2.49 degrees after walking with talus taping²¹⁾. The results of our present study show that passive DFROM with 0 degree knee flexion was 6.04 \pm 3.46 before orthosis, and 13.77 \pm 3.31 after orthosis (the effect size was 2.28). These results suggest that treadmill walking with an ASO may mimic the manual mobilization of the MWM and TST techniques.

Our results also show that treadmill walking with the ASO increased maximum ankle dorsiflexion before heel-off and time to heel-off during the stance phase of gait. Previous studies have shown that decreased ankle dorsiflexion result in early heel-off⁷⁾, subtalar joint pronation, and midtarsal joint dorsiflexion⁶⁾ during gait. Early heel-off may increase weight-bearing on the forefoot during the stance phase of gait. Furthermore, increased loading of the forefoot is a

cause of lower-extremity overuse injury⁸). Previous studies have reported that TST increases ankle dorsiflexion before heel-off and prolongs the time to heel-off during the stance phase of gait²¹), and that the time to heel-off significantly prolonged by 5 minutes walking with TST¹⁸). Because the time to heel-off constitutes about two thirds of the stance phase during normal gait, increase of the time to heel-off is regarded as an important element in the restoration of a normal gait pattern. Cornwall et al.⁷) demonstrated that individuals with restriction of dorsiflexion ROM showed decreased time to heel-off, while another study reported that decreased time to heel-off may result in an increase in the proportion of the stance time increase spent weight-bearing on the forefoot²²).

We demonstrated the effect of treadmill walking with an ASO on ankle dorsiflexion ROM and gait pattern. Treadmill walking with the ASO prolonged the time to heel-off during the stance phase of gait and increased active and passive DFROM, and the lunge angle. There was also an increase in the angle of maximal dorsiflexion before the stance phase. According to the results of the present study, treadmill walking with the orthosis facilitated ankle flexibility and improved the kinematics of the ankle during walking via an increase in dorsiflexion ROM and prolongation of the time to heel-off. The present study provides evidence that treadmill walking with the ASO is a beneficial intervention for improving ankle flexibility and abnormal kinematics of the ankle during walking by individuals with limited ankle dorsiflexion ROM.

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