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Original Article

Elucidation of abductor digiti minimi activity in chronic ankle instability

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Abstract. [Purpose] This study aimed to compare the muscle activity around the foot and ankle joints, notably of the abductor digiti minimi, between affected and unaffected sides of individuals with chronic ankle instability. [Participants and Methods] Twelve adult males with chronic ankle instability in one ankle (age, 27.7 ± 5.4 years; height, 172.5 ± 8.1 cm; weight, 67.5 ± 8.1 kg) were included and underwent surface electromyography assessments in multiple positions on both affected and unaffected sides. Measurements were obtained for eight muscles including the abductor digiti minimi. Each measurement included a 5-s segment of the stable waveform, with the root mean square-processed and normalized to the resting position set to 1. [Results] Abductor digiti minimi activity on the affected side was significantly reduced during maximal toe extension/abduction with both ankle dorsiflexion and plantarflexion. Peroneus longus activity on the affected side was significantly greater during maximal toe extension/abduction with ankle plantarflexion; peroneus longus and tibialis anterior muscle activities were significantly greater on the affected side during maximal toe extension/abduction with ankle dorsiflexion. [Conclusion] In the absence of load, muscle imbalance in the intrinsic and extrinsic muscles of the foot was suggested. However, no significant differences were observed under loading conditions.
Key words: Chronic ankle instability, Abductor digiti minimi, Muscle activity

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INTRODUCTION

Lateral ligamentous injury of the ankle joint is one of the most common sports injuries[1)], and it often persists as long-term chronic ankle instability (CAI) with pain after the injury[2)]. In assessments of the muscle activity after an ankle sprain, peroneus longus activity was shown to increase on ambulation; this phenomenon is thought to be caused by dysfunction of the plantarflexion inversion muscles and the proprioceptors[3)]. In contrast, the activities of the gluteus medius and erector spinae increased to compensate for the reduced ankle joint muscle function in balance[4)]. Angin et al. reported that flat feet showed increased activity of the extrinsic foot muscles and reduced activity of the intrinsic muscles[5)]. Thus, CAI-induced changes in systemic muscle activity patterns cause muscle imbalance[6)], which can lead to further functional deterioration and secondary disability.

Nevertheless, to our knowledge, a few studies have discussed the activity of the intrinsic muscles of the foot after a sprain injury. One of these studies reported that the dynamic balance in individuals with CAI was improved by exercising the intrinsic foot muscles[7)]. The abductor digiti minimi is considered to be the lateral longitudinal arch constituent muscle, and

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atrophy of this muscle has been reported in hyperpronated feet[8], as well as in flat feet[9]. Thomas et al. stated that the abductor digiti minimi is activated on training the intrinsic foot muscles[10]; however, the activities of this muscle in individuals with CAI have not been clarified.

Therefore, in this study, we aimed to clarify how the activities of muscles around the ankle joint, including the abductor digiti minimi, were affected by CAI. To this end, we investigated the differences in the activities of muscles around the ankle joints, including the abductor digiti minimi, between the non-CAI and the CAI sides during various exercise tasks with and without loads.

PARTICIPANTS AND METHODS

The participants included 12 adult males (age, 27.7 ± 5.4 years; height, 172.5 ± 8.1 cm; weight, 67.5 ± 8.1 kg) who met the recommended criteria[11] of the International Ankle Consortium for CAI in one ankle joint. Prior to the experiment, the participants were fully informed of the procedure, purpose, and risks of this experiment, and consent was obtained. This experiment was conducted with the approval of the Ethics Committee of the Kanazawa Orthopedic Clinic (Kanazawa-OSMC-2018-001).

The participants were asked to take the following 10 positions on both the CAI and the non-CAI sides: one-leg standing; one-leg toe-standing (100%); toe-standing with 20%, 40%, 60%, and 80% loads; end-sitting position with the ankle dorsiflexed or plantarflexed and toes maximally extended/abducted or toes maximally flexed. One-leg standing and one-leg toe-standing were performed without hand support, and the participants were instructed to look straight ahead. For toe-standing with 20%, 40%, 60%, and 80% loads, participants were asked to toe-stand on both feet using a weight scale. Once we confirmed that the weight had been properly transferred to the measuring leg, we started our measurements. The measurements in the end-sitting position were performed at a height at which the feet did not touch the floor, and the participants were instructed to maintain a straight posture. The surface electromyograms during these 10 positions were measured on the CAI and non-CAI sides. Measurements were obtained for the following muscles: abductor digiti minimi, abductor hallucis, peroneus longus/brevis, tibialis anterior, medial and lateral heads of the gastrocnemius, and soleus.

Surface electromyograms were recorded using an active electrode (MQ8/16 16-bit EMG amplifier; Kissei Comtec, Matsumoto, Nagano, Japan). The distance between the electrodes was 10 mm, the electrode size was 10 mm × 10 mm, and the electromyographic signal was recorded by a telemetry system (MQ16) at a sampling frequency of 1,000 Hz (16-bit). The electromyographic data were collected on a personal computer and processed using analysis software (Kine Analyzer; Kissei Comtec, Japan). For the abductor digiti minimi, electrode attachment was performed in a longitudinal direction from a site 10 mm anterior to the calcaneus. In addition, based on the findings reported by Hermens et al.[12] (SENIAM, Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) and Mortka et al.[13], electrodes were attached to the following sites: at the center of the muscle belly for the abductor hallucis, the proximal one-third between the tip of the fibula and the tip of the medial malleolus for the tibialis anterior, the proximal one-fourth between the fibular head and the tip of the lateral malleolus for the peroneus longus, the distal one-fourth between the fibular head and the tip of the lateral malleolus for the peroneus brevis, above the bulge of the muscle belly for the medial gastrocnemius, the proximal one-third between the fibular head and heel for the lateral head of the gastrocnemius, and the distal one-third between the medial condyle of the fibula and the medial malleolus for the soleus.

Measurements for each position were recorded for 10 s, from which 5 s of data with stable waveforms were extracted. After root mean square (RMS) processing, results were normalized with the resting position set to 1. For statistical processing, a paired t-test was used. The significance level was set to 5% or less. SPSS software (version 21.0: manufactured by IBM, Tokyo, Japan) was used for statistical processing.

RESULTS

Table 1 shows the electromyogram activity in each position.

The abductor digiti minimi activity on the CAI side significantly decreased upon maximal toe extension/abduction, with both ankle dorsiflexion and plantarflexion. Moreover, peroneus longus activity was significantly greater on the CAI side during maximal toe extension/abduction with ankle plantarflexion and dorsiflexion. During maximal toe flexion with ankle plantarflexion, the peroneus longus muscle activity was significantly greater on the CAI side. The tibialis anterior muscle activities were significantly greater on the CAI side during maximal toe extension/abduction with ankle dorsiflexion. Moreover, tibialis anterior muscle was greater on the CAI side during toe-standing with loads of 20%. Toe-standing with loads of 20%, 40% and 60% showed a significant reduction in the activity of the lateral head of the gastrocnemius on the CAI side. In addition, no significant difference was observed between one-leg standing, one-leg toe-standing, and toe-standing positions with a load of 80% and toe flexion with ankle dorsiflexion.

Table 1. Electromyogram activity in each position

	Abductor digiti minimi		Abductor pollicis longus		Peroneus brevis		Peroneus longus		Tibialis anterior		Medial head of gastrocnemius		Lateral head of gastrocnemius		Soleus	
	CAI side	Non-CAI side	CAI side	Non-CAI side	CAI side	Non-CAI side	CAI side	Non-CAI side	CAI side	Non-CAI side	CAI side	Non-CAI side	CAI side	Non-CAI side	CAI side	Non-CAI side
One-leg standing	12.2 ± 7.2	11.5 ± 7.6	38.4 ± 20.1	35.1 ± 23.4	35.4 ± 24.8	35.0 ± 15.4	31.4 ± 10.7	29.4 ± 25.4	13.7 ± 9.5	15.5 ± 17.3	19.8 ± 12.5	20.5 ± 18.4	10.8 ± 7.4	14.7 ± 9.5	16.1 ± 11.6	16.6 ± 7.1
One-leg toe standing	37.7 ± 19.1	43.1 ± 23.8	38.4 ± 18.4	42.2 ± 28.0	78.2 ± 39.1	89.3 ± 37.3	55.8 ± 27.3	56.1 ± 28.1	22.2 ± 18.0	19.8 ± 22.8	60.7 ± 26.7	54.1 ± 27.8	25.3 ± 20.8	26.0 ± 11.5	40.2 ± 32.2	41.5 ± 25.5
Toe standing with 20% load	7.1 ± 8.0	10.7 ± 16.9	9.9 ± 8.4	5.8 ± 5.8	14.2 ± 8.5	14.6 ± 11.0	13.5 ± 7.2	11.7 ± 8.4	**2.4 ± 1.2***	1.8 ± 1.3	13.4 ± 7.7	14.7 ± 6.5	**3.8 ± 1.9***	6.6 ± 5.5	12.2 ± 10.6	11.0 ± 8.7
Toe standing with 40% load	10.6 ± 10.6	10.7 ± 11.9	11.4 ± 6.7	15.2 ± 20.2	22.0 ± 18.3	26.2 ± 17.0	16.5 ± 7.9	14.4 ± 8.5	2.9 ± 1.7	2.2 ± 1.5	19.4 ± 10.2	17.2 ± 6.5	**5.1 ± 2.3***	9.0 ± 5.9	16.5 ± 13.0	14.9 ± 10.2
Toe standing with 60% load	14.6 ± 12.2	12.7 ± 13.3	17.3 ± 15.1	14.2 ± 16.9	27.4 ± 21.5	30.3 ± 20.1	21.1 ± 12.3	17.1 ± 9.4	5.0 ± 4.9	5.3 ± 7.3	26.4 ± 12.4	25.1 ± 10.0	**8.4 ± 5.0***	12.4 ± 7.2	19.8 ± 15.0	18.1 ± 11.9
Toe standing with 80% load	19.9 ± 16.0	22.3 ± 18.8	26.0 ± 18.3	22.5 ± 17.1	38.6 ± 20.4	51.4 ± 27.1	29.5 ± 22.2	25.0 ± 15.5	5.2 ± 2.3	5.8 ± 6.1	36.6 ± 16.9	36.8 ± 18.3	12.2 ± 7.1	19.4 ± 11.1	23.8 ± 20.3	20.8 ± 12.9
Toe extension with ankle dorsiflexed	**3.6 ± 1.9***	11.0 ± 11.7	9.3 ± 18.5	7.1 ± 10.6	14.2 ± 13.7	9.1 ± 5.7	**12.1 ± 6.9***	8.6 ± 6.9	**70.2 ± 57.5***	46.1 ± 41.6	4.6 ± 5.8	3.7 ± 2.5	3.1 ± 2.8	2.4 ± 1.1	6.9 ± 5.3	5.7 ± 3.7
Toe flexion with ankle dorsiflexed	5.6 ± 7.9	4.8 ± 4.5	4.3 ± 3.8	2.9 ± 1.7	12.0 ± 10.0	9.3 ± 4.9	8.5 ± 5.4	6.1 ± 3.2	80.3 ± 46.1	63.0 ± 44.3	3.2 ± 1.6	2.9 ± 1.4	2.5 ± 2.1	2.3 ± 1.1	8.2 ± 7.8	8.8 ± 7.9
Toe extension with ankle plantarflexed	**9.8 ± 3.6***	12.5 ± 20.2	12.4 ± 16.3	11.7 ± 10.8	18.4 ± 37.0	18.9 ± 23.7	**13.6 ± 17.2***	11.2 ± 17.6	23.3 ± 4.7	18.9 ± 3.7	13.2 ± 6.8	12.1 ± 5.6	4.7 ± 7.6	7.0 ± 8.5	13.3 ± 7.8	11.2 ± 10.1
Toe flexion with ankle plantarflexed	10.5 ± 9.5	11.0 ± 9.7	10.5 ± 5.6	9.8 ± 13.7	32.9 ± 17.6	30.9 ± 14.2	**32.5 ± 13.1***	23.9 ± 13.1	5.3 ± 3.2	12.6 ± 26.0	15.1 ± 12.8	10.0 ± 6.5	10.4 ± 6.7	10.3 ± 7.3	18.9 ± 15.2	24.2 ± 32.1

Mean ± standard deviation.
*$p<0.05$.
CAI: chronic ankle instability.
The RMS value was calculated and normalized with the resting position set to 1.

DISCUSSION

In this study, we investigated the differences in the activity levels of muscles around the ankle joint, including the abductor digiti minimi, on the non-CAI and CAI sides during various exercise tasks with and without loads. The muscle activity of the abductor digiti minimi with the ankle plantarflexed/dorsiflexed and toe extended/abducted without any load was shown to be less on the CAI side than on the non-CAI side. However, the muscle activity of the abductor digiti minimi did not significantly differ between the non-CAI and CAI sides in the one-leg standing and toe-standing tasks with loads. Moreover, among ankle muscles other than the abductor digiti minimi, during the exercise task with toes extended/abducted and flexed without any loads and the ankle plantarflexed, the peroneus longus showed significantly greater activity on the CAI side than on the non-CAI side. In addition, during the toe extension/abduction exercise task with the ankle dorsiflexed and without load, the activities of the peroneus longus and tibialis anterior were significantly greater on the CAI side than on the non-CAI side. In one-leg toe-standing tasks with loads of 20%, 40%, and 60%, the activity of the lateral head of the gastrocnemius on the CAI side was significantly lesser than that on the non-CAI side.

The results of this study suggest that CAI may cause imbalance in the muscles around the ankle joint. Muscle imbalance is a condition in which certain muscles overreact due to minute damage or physical stress, suppressing the activity of the antagonist muscle and promoting an incorrect movement/posture pattern[6]. This study showed that during exercise tasks involving toe extension/abduction performed under ankle plantarflexion/dorsiflexion, the activity of the abductor digiti minimi decreased on the CAI side, and the activities of the peroneus longus and tibialis anterior increased. Thus, muscle imbalance on the CAI side occurs between the abductor digiti minimi, an intrinsic foot muscle, and the peroneus longus and tibialis anterior, both of which are extrinsic foot muscles. These results are consistent with the findings reported by Angin et al., who showed that the extrinsic muscles compensated for the decline in intrinsic muscle function in flat feet[5]. Therefore, individuals with CAI would have to excessively control ankle inversion and plantarflexion exercises that would be constantly unstable due to CAI. As such, it is likely that extrinsic muscles of the foot, such as the peroneus longus and tibialis anterior, cause excessive activity. Furthermore, the excessive activity of these extrinsic muscles of the foot suppresses the activity of the abductor digiti minimi, an intrinsic muscle of the foot. This mechanism is likely responsible for the imbalance of muscles around the ankle joint on the CAI side.

The tasks with loads did not show muscle imbalance between the abductor digiti minimi (intrinsic muscle of the foot) and peroneus longus and tibialis anterior (extrinsic muscles of the foot) as noted on the CAI side during the non-load toe extension/abduction exercise task with ankle plantarflexion/dorsiflexion. However, a significant decrease in the activity of the lateral head of the gastrocnemius was observed on the CAI side in the one-leg toe-standing tasks with loads of 20%, 40%, and 60%. The absence of the muscle imbalance between the abductor digiti minimi and the peroneus longus and the tibialis anterior was likely because the load task in this study did not require foot arch formation or control in the medial/lateral direction. For the gastrocnemius, an extrinsic foot muscle, there was no difference in the activity of the medial head on the non-CAI and CAI sides. However, the lateral head did show a difference in activity, suggesting that muscle imbalance may occur even within the same muscle because roles differ by location.

Since this study targeted only adult males and did not clarify the muscle activities in females, the elderly, and young people, the scope of these investigations should be expanded by broadening the target population in future studies. In addition, according to a study by Fukano et al., the lateral longitudinal arch shows a large angular change in the landing motion[14]. The activity of the abductor digiti minimi in the dynamic phase, such as in landing and turning motions, which constitute the lateral ligament injury mechanism, should be measured to further clarify the muscle function characteristics. In this study, it was found that in the ankle joint with CAI, the abductor hallucis longus muscle activity was decreased and the peroneus longus and tibialis anterior muscles were overactive. In addition, muscle imbalance between the intrinsic and extrinsic muscles of the foot may occur.

Funding and Conflict of interest

None.

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