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Original Article

Changes in ground reaction force during a rebound-jump task after hip strength training for single-sided ankle dorsiflexion restriction

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Abstract. [Purpose] Lateral ankle sprains are common injuries suffered while playing sports, and abnormal forward- and inward-directed ground reaction force occurs during a jumping task. However, the influence of hip muscle strength training on jumping performance after ankle injuries has not been fully examined. This study thus examined changes in ground reaction force during a rebound-jump task after training to strengthen hip muscles. [Subjects and Methods] Ten of 30 female high school basketball players were assigned as subjects who showed a difference of 7 or more degrees in dorsiflexion ranges between the bilateral ankles. The subjects underwent 12 weeks of training to strengthen hip abductors and external rotators. Comparisons between before and after training were made regarding ground reaction force components, hip and knee joint angles, percentage of maximum voluntary contraction in leg muscles, and muscle strength of hip muscles during the rebound-jump task. [Results] After training, the subjects showed increased strength of external rotator muscles, increased percentage of maximum voluntary contraction in the gluteus medius muscle, decreased inward ground reaction force, and increased flexion angles of the hip and knee joints. [Conclusion] This study suggests that training to strengthen hip muscles may ameliorate the inward ground reaction force in athletes with ankle dorsiflexion restriction.

Key words: Ankle dorsiflexion restriction, Strength training, Hip flexion angles

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INTRODUCTION

Lateral ankle sprains or injuries to the lateral ligaments of the ankle complex are commonly suffered while playing sports[1–5)], and Hosea et al.[6)] reported that female interscholastic and intercollegiate basketball players had a 25% greater risk of incurring grade I ankle sprains than their male counterparts. Moreover, recurrence rates were reported to exceed 70% in sports such as basketball[7, 8)]. After an ankle sprain, three potential ankle factors chronically worsened: proprioceptive deficits, muscle weakness, and ligamentous laxity[9)]. Chronic ankle instability caused significantly less dorsiflexibility (4.8 ± 0.6 degrees) than in controls during jogging[10)]. Gribble et al.[11)] reported that subjects with chronic ankle instability had deficits of torque in the ankle plantar flexor and in the knee flexor and extensor, but no similar deficits in the hip.

However, Negahban et al.[12)] reported that the average peak torque to body weight ratio in ankle dorsiflexor or hip flexor muscles was significantly lower in chronic ankle instability subjects than in healthy controls. Additionally, a significant delay in the onset of activation of the gluteus maximus was found in subjects with ankle sprain[13)]. It was suggested that this delay was due to changes in proximal muscle function and local sensory function[14)]. Thus, laxity at the ankle joint could involve hip

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kinematics related to the change in balance strategy from an ankle strategy to a hip strategy[15–17]. For example, subjects with ankle instability showed a less externally rotated position of the hip joint at the initial contact of jump landing[18]. Moreover, ankle dorsiflexion restriction produced a decreased peak knee flexion angle, increased knee valgus angle, and medial knee displacement compared with cases without restriction during a squat task[19].

In healthy subjects, increased hip abduction and external rotation strength improved the performance of single-leg squats[20]. However, the influence of hip muscle strength training on jumping performance after ankle injuries has not been fully examined. In terms of ground reaction force, subjects with ankle instability showed a significant increase in posteriorly and medially directed forces after initial contact during a jump landing task[18]. As repetitive malalignment stimulations on the ankle joints likely cause arthritis[21, 22], it may be important to reduce abnormally directed ground reaction force by means of an intervention. The current study was thus conducted based on the hypothesis that increased strength of the hip abductors and external rotators may be effective in correcting the direction of ground reaction forces in female basketball players with ankle dorsiflexion restriction.

SUBJECTS AND METHODS

Subjects

Ten of 30 national-level female high school basketball players were assigned as subjects (age, 15.9 ± 1.1 years; weight, 57.9 ± 3.3 kg; height, 165.2 ± 4.6 cm; mean ± SD) in this study because of a difference of 7 or more degrees (8.8 ± 1.3 degrees, mean ± SD) in dorsiflexion ranges between the bilateral ankles. The reason for this selection was that Ota et al.[23] reported that the knee kinematics and kinetics were affected by a reduced ankle dorsiflexion range of approximately 8 degrees during gait. Previous injuries included the following: two cases of ankle inversion sprain, one case of Achilles tendinitis, and one case of adductor muscle contusion on the restricted side. Exclusion criteria included previous knee injuries and a postoperative state of the ankle joints. As per the Declaration of Helsinki, the subjects' written consent and approval of the Ethics Committee of Nittazuka Medical Welfare Center (approval no. 23-1) were obtained prior to the study. No subjects dropped out during the course of the study.

Methods

Rebound-jump tasks were performed three times from a 30-cm-high[24–27] step platform (Training Chair K3340M, Minato Medical Science Co., Ltd.) to a ground reaction force plate with goniometers and surface electrodes on the limb side with ankle restriction (Fig. 1). Regarding the ground reaction force components, Fx, Fy, and Fz were measured using a force plate (9286A; Kistler). They were recorded as positive (+) in the outward, forward, and upward directions and negative (−) in the inward, backward, and downward directions for each component, respectively. The component values were divided by body weight and normalized to calculate %Fx, %Fy, and %Fz. The landing point was initially identified based on the Fz value recorded on the ground reaction force plate to classify it into the following five points and to calculate the mean ground reaction force component values and joint angles (Fig. 2): 1) the landing point, the first peak of the Fz value after landing; 2) the impact-absorbing point, the bottom peak of the Fz value after landing; 3) the disturbance response point, the second peak of the Fz value between the impact-absorbing and unweighting points; 4) the unweighting point, the lowest Fz value after

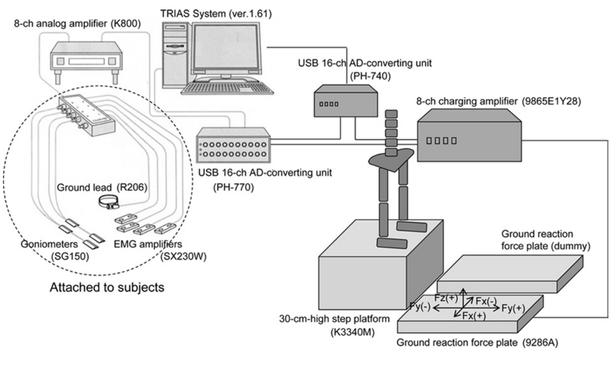

Fig. 1. Measurement system and wiring diagram
Biaxial goniometers and surface electrodes were attached to the leg with ankle restriction. Rebound-jump tasks were performed from a 30-cm-high step platform to two ground reaction force plates; one of them was for the leg with ankle restriction, and the other was a dummy for the opposite leg. This figure presents the measurement system for a subject with restriction in the right ankle.

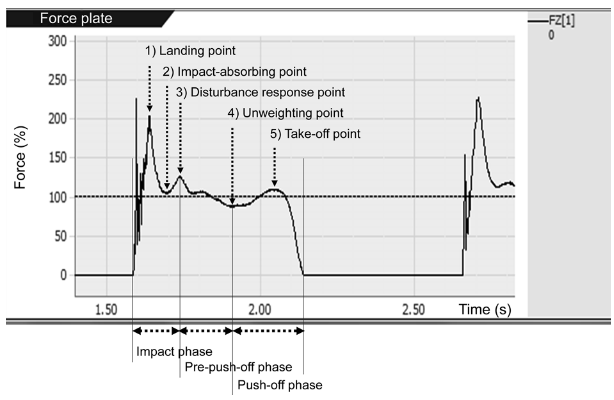

Fig. 2. Points and phases during a rebound-jump task identified based on the Fz value
The horizontal axis represents time in seconds, and the vertical axis represents the upward ground reaction force divided by body weight.

landing; and 5) the take-off point, the Fz value marked immediately before taking off. In addition, to evaluate the relative myoelectric activity, the rebound-jump task was classified into the following three phases: the impact phase, from the landing to disturbance response points; pre-push-off phase, from the disturbance response to unweighting points; and push-off phase, from the unweighting to take-off points.

Biaxial goniometers (SG150, Biometrics Co., Ltd.) were attached to the lateral side of the hip joint and knee joint of the ankle-restricted leg. Flexion/extension and abduction/adduction in the hip joint and flexion/extension and valgus/varus in the knee joint were measured. Hip and knee flexion in the sagittal plane was recorded as positive (+), and hip and knee extension in the sagittal plane was recorded as negative (−). Hip abduction and knee varus in the frontal plane were recorded as positive (+), and hip adduction and knee valgus in the frontal plane were recorded as negative (−). The measured angles were considered those projected in the sagittal and frontal planes. A Butterworth low-pass filter was used at a cut-off frequency of 15 Hz for waveform processing of each angle[24, 28, 29]. To measure muscle activity, surface electrodes (SX230W, Biometrics Co., Ltd.) were attached to the gluteus maximus, gluteus medius, vastus medialis, and vastus lateralis muscles on the measurement side[30], while a ground electrode (R206, Biometrics Co., Ltd.) was attached to the ulnar styloid process on the same side. Waveform data were processed within a band-pass range of 20 to 450 Hz and fully rectified to calculate integrals during the rebound-jump task and means per unit time. EMG data for maximum voluntary contraction (MVC) were recorded from the gluteus maximus muscle while the subjects performed maximum isometric voluntary hip extension at 0 degrees of hip extension and 90 degrees of knee flexion in a prone position, from the gluteus medius muscle while the subjects performed maximum isometric voluntary hip abduction at 0 degrees of hip abduction in a side-lying position, and from the vastus medialis and vastus lateralis muscles while the subjects performed maximum isometric voluntary knee extension at 60 degrees of knee flexion in an upright sitting position against manual resistance for 6 s. The mean integrals of the middle 3 s were used to obtain before and after training MVCs. Muscle activities are presented as relative values percentage of MVC; %MVC during each phase of the rebound-jump task. All ground reaction force components, joint angles, and muscle activity were synchronized using a TRIAS device (TRIAS System ver. 1.61, DKH Co., Ltd.) and recorded at a sampling frequency of 1 kHz.

Hip abductor and external rotator muscle strengths were evaluated at angular velocities of 0, 60, and 90 degrees/s using CYBEX Norm (CYBEX Corporation). While abduction tasks were performed in a side-lying position to facilitate the gluteus medius muscle output, rotations were performed in an upright sitting position with the hip flexed to confirm muscle strength changes. The muscle strength was divided by the body weight for comparison.

Following the initial evaluation, the subjects underwent training to strengthen hip abductors and external rotators on both sides. Hip abductors were trained by laterally raising the leg in a side-lying position while keeping the hip and knee joints straight without trunk rotation. Hip external rotators were also trained by outwardly rotating the hip joint in a side-lying position but with 45 degrees of hip joint flexion and 90 degrees of knee joint flexion. One repetition maximum of each movement was measured using a handheld dynamometer (PowerTrack II MMT Commander, Nihon Medix Co., Ltd.), at one-third distal of the thigh. One set of training consisted of 10 repetitions at 70% intensity, as monitored using the dynamometer. The dynamometer was handled by members of the team under our supervision during training. A set was performed in approximately 10 s, and five sets were performed with 2 min of rest between the sets. The training was conducted three times a week for 12 weeks after regular team training after school.

Paired t-tests were performed to examine the difference in measurements between before and after training for muscle strength, muscle activities, ground reaction forces, and joint angles. The significance level was set at less than 5% of the risk rate. For statistical analysis, add-in software (4-Step Excel Statistics ver. 3, OMS Publishing Inc.) was installed within Microsoft Office Excel 2010.

RESULTS

The strength of external rotator hip muscles increased at an angular velocity of 0 degree/s after training (81.0 ± 12.6 Nm/kg vs. 64.9 ± 15.4 Nm/kg, $p<0.05$) (Table 1). The %MVC of the gluteus medius muscle significantly increased during the pre-push-off (46.6 ± 24.9% vs. 25.6 ± 14.2%, $p<0.05$) and push-off phases (103.3 ± 39.4% vs. 74.1 ± 24.5%, $p<0.05$) after training (Table 2).

The inward component decreased at the impact-absorbing (−9.1 ± 4.7% vs. −12.0 ± 3.1%, $p<0.05$) and take-off points (−15.9 ± 3.6% vs. −18.4 ± 3.8%, $p<0.05$) (Table 3). The upward component of the subjects increased at the unweighting point (93.2 ± 17.7% vs. 79.0 ± 5.5%, $p<0.05$).

The hip flexion angle significantly increased at all points (landing point, 59.2 ± 14.4 degrees vs. 44.6 ± 11.4 degrees, $p<0.05$; impact-absorbing point, 77.4 ± 13.1 degrees vs. 61.8 ± 13.2 degrees, $p<0.05$; disturbance response point, 89.8 ± 13.3 degrees vs. 73.6 ± 12.4 degrees, $p<0.05$; unweighting point, 89.3 ± 17.0 degrees vs. 82.1 ± 12.5 degrees, $p<0.05$; take-off point, 63.1 ± 20.0 degrees vs. 48.4 ± 10.9 degrees, $p<0.05$) (Table 4). Furthermore, the knee flexion angle also significantly increased at the landing (54.0 ± 11.3 degrees vs. 46.5 ± 7.2 degrees, $p<0.05$) and take-off points (68.9 ± 9.8 degrees vs. 61.6 ± 5.5 degrees, $p<0.05$) after training. The hip and knee angles in the frontal plane did not change.

Table 1. Strength of hip abductors and external rotators at each angular velocity (n = 10)

		Before training, Nm/kg	After training, Nm/kg
Hip abductor strength	0 degree/s	145.7 ± 33.1	149.1 ± 26.6
	60 degrees/s	111.3 ± 25.0	121.4 ± 22.0
	90 degrees/s	103.0 ± 19.6	109.8 ± 23.7
Hip external rotator strength	0 degree/s	64.9 ± 15.4	81.0 ± 12.6*
	60 degrees/s	61.0 ± 13.8	62.4 ± 13.8
	90 degrees/s	54.0 ± 10.0	55.7 ± 12.3

Values are divided by body weight and are expressed as the mean ± SD. *p<0.05 between before and after training.

Table 2. Activity of thigh muscles in each phase (%MVC) (n = 10)

		Before training, %	After training, %
Gluteus maximus	Impact phase	71.9 ± 73.9	61.2 ± 34.8
	Pre-push-off phase	81.1 ± 74.7	126.6 ± 91.8
	Push-off phase	111.2 ± 103.6	125.3 ± 74.5
Gluteus medius	Impact phase	35.7 ± 17.2	53.4 ± 40.0
	Pre-push-off phase	25.6 ± 14.2	46.6 ± 24.9*
	Push-off phase	74.1 ± 24.5	103.3 ± 39.4*
Vastus medialis	Impact phase	145.8 ± 62.9	148.1 ± 47.0
	Pre-push-off phase	133.9 ± 45.5	158.2 ± 65.4
	Push-off phase	164.8 ± 36.0	201.2 ± 79.6
Vastus lateralis	Impact phase	143.2 ± 51.3	158.0 ± 56.8
	Pre-push-off phase	118.0 ± 44.5	146.2 ± 48.1
	Push-off phase	185.0 ± 71.0	200.5 ± 68.0

Values are relative values of maximum voluntary contraction and are expressed as the mean ± SD. *p<0.05 between before and after training.

Table 3. Three components of ground reaction force at each point (n = 10)

		Before training, %	After training, %
Outward/inward components (Fx)	Landing point	−11.6 ± 7.9	−7.8 ± 9.4
	Impact-absorbing point	−12.0 ± 3.1	−9.1 ± 4.7*
	Disturbance response point	−10.5 ± 2.9	−11.0 ± 4.3
	Unweighting point	−6.2 ± 9.1	−10.3 ± 4.4
	Take-off point	−18.4 ± 3.8	−15.9 ± 3.6*
Forward/backward components (Fy)	Landing point	−23.3 ± 12.2	−22.6 ± 14.9
	Impact-absorbing point	24.9 ± 6.1	22.4 ± 4.7
	Disturbance response point	2.5 ± 5.6	0.9 ± 4.1
	Unweighting point	0.1 ± 5.1	−0.4 ± 3.4
	Take-off point	8.2 ± 3.2	6.6 ± 3.5
Upward/downward components (Fz)	Landing point	217.2 ± 45.4	233.3 ± 29.6
	Impact-absorbing point	86.6 ± 8.0	89.2 ± 7.0
	Disturbance response point	111.4 ± 11.6	121.0 ± 17.6
	Unweighting point	79.0 ± 5.5	93.2 ± 17.7*
	Take-off point	110.3 ± 8.2	111.7 ± 9.5

Values are divided by body weight and are expressed as the mean ± SD. *p<0.05 between before and after training.

Table 4. Hip and knee angles in the sagittal and frontal planes at each point (n = 10)

		Before training, degrees	After training, degrees
Hip angle			
In the sagittal plane	Landing point	44.6 ± 11.4	59.2 ± 14.4*
	Impact-absorbing point	61.8 ± 13.2	77.4 ± 13.1*
	Disturbance response point	73.6 ± 12.4	89.8 ± 13.3*
	Unweighting point	82.1 ± 12.5	89.3 ± 17.0*
	Take-off point	48.4 ± 10.9	63.1 ± 20.0*
In the frontal plane	Landing point	8.3 ± 5.2	9.9 ± 9.1
	Impact-absorbing point	6.2 ± 13.6	8.2 ± 11.4
	Disturbance response point	5.6 ± 16.1	7.5 ± 15.7
	Unweighting point	12.0 ± 16.9	11.1 ± 15.9
	Take-off point	4.1 ± 8.2	10.5 ± 11.4
Knee angle			
In the sagittal plane	Landing point	46.5 ± 7.2	54.0 ± 11.3*
	Impact-absorbing point	69.0 ± 8.8	74.7 ± 12.2
	Disturbance response point	81.1 ± 7.9	85.7 ± 10.6
	Unweighting point	85.6 ± 10.8	88.7 ± 9.1
	Take-off point	61.6 ± 5.5	68.9 ± 9.8*
In the frontal plane	Landing point	−9.3 ± 6.2	−9.4 ± 3.5
	Impact-absorbing point	−3.2 ± 7.7	−0.8 ± 5.3
	Disturbance response point	−0.1 ± 7.7	4.1 ± 8.0
	Unweighting point	4.8 ± 8.4	5.1 ± 11.4
	Take-off point	−5.5 ± 8.3	−5.3 ± 6.8

Values are expressed as the mean ± SD. *p<0.05 between before and after training.

DISCUSSION

In this study, the inward direction component of the ground reaction force was significantly ameliorated in subjects with ankle dorsiflexion restriction after hip abduction and external rotation muscle training. For an initial explanation of the kinetic change, it seemed important to consider the hip and knee angles during the rebound-jump task. The change in ground reaction force was observed at the impact-absorbing point and the take-off point, where the hip flexion angle and the knee flexion angle somewhat increased, as shown by the angles in the sagittal plane. There was no significant difference in hip and knee angles in the frontal plane in this study, but the values for the hip angle in the frontal plane tended to be larger, which indicated further hip abduction, and the knee tended to be in varus after training. It was suggested that deeper bending of the hip and knee joints with slightly further hip abduction could correct the valgus of the knee to an extent that would not appear in the change in angle. A previous study reported that 8 weeks of lower extremity training, such as with bilateral and unilateral squats, lunges, step-ups, and Romanian deadlifts, induced a significant increase in knee flexion angle during the drop vertical jump task; however, significant differences in knee valgus and hip flexion angles were not shown[31)]. Even if the knee angle changed from valgus to varus, it might not be detected as a statistically significant change by the present method.

As another possible explanation, the corrective reaction on the inward direction component might be explained by increased external rotational muscular strength of the hip joint and improved utilization of the gluteus medius muscle. Generally, the hip external rotation muscles have been reported to be the obturator externus, quadratus femoris, and iliopsoas muscles when the hip joint is flexed 40 degrees or more[32, 33)]. In particular, as external rotational muscular strength training was performed with 45 degrees of hip joint flexion, the stability of the hip joint was possibly increased in a flexed position by the external rotation muscles.

Additionally, the gluteus medius muscle was shown to produce an internal rotation moment around the hip joint when the hip was flexed more than 40 degrees[32, 33)]. Increased activity of the gluteus medius muscle was also suggested to assist hip stabilization and pelvic rotation besides hip abduction[34)]. In the present study, the range of hip flexion angle was 59–89 degrees at each measurement point of the rebound-jump task after training, and internal rotation of the hip joint by the gluteus medius muscle might induce more stability of the hip joint during hip joint external rotation.

A previous program to prevent injury after ankle sprain focused on decreasing hip adductor activity and increasing hip abductor and external rotator activities[35)]. We intended to follow this program and could show the compensatory movements of the hip and knee flexion and simultaneous reduction of the inward component of ground reaction force. Consequently, muscle strength training around the hip joint may be useful for improving movement during the rebound jump.

There are some limitations to the present study. We could show the difference in ground reaction force between before and after training in the subjects; however, precise compliance and reliability of the training technique in the high school students could not be shown even though the method was well directed by a physical therapist during the training. Generally, 12 weeks of training at 70% intensity of muscle strength is suggested to be sufficient to increase muscle strength. The result of no increase in hip abductor muscle strength may have been due to an inaccurate hip flexion training position or some other reason. As we evaluated muscle strength only in the hip abductor and external rotator muscles, the effect of other hip muscles on the rebound-jump task was obscure.

The current study examined changes in ground reaction force in ankle dorsiflexion restriction during a rebound-jump task following 12 weeks of training to strengthen hip abductors and external rotator muscles. This study suggests that training may have been effective to increase the muscle strength of external rotators and gluteus medius muscle activity, which resulted in increased hip and knee joint flexion angles and reduced inward ground reaction force at the impact-absorbing and take-off points in ankle dorsiflexion restriction.

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