

Original Article

Strength Training for the Intrinsic Flexor Muscles of the Foot: Effects on Muscle Strength, the Foot Arch, and Dynamic Parameters Before and After the Training

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Abstract. [Purpose] The purpose of the present study was to verify the effects of intrinsic foot flexor strength training. [Subjects] The subjects were 12 healthy males without motor system disease. [Methods] A training method that involved flexion of all toe interphalangeal and metatarsophalangeal joints against a 3-kg load was implemented and was performed for 200 repetitions once per day, three times per week, for a period of eight weeks. [Results] Significant changes were observed for intrinsic foot flexor strength scores, foot arches, vertical jumping, 1-legged long jumping, and 50-m dash time. [Conclusion] This muscle strength training method significantly improved muscle strength scores, foot arch shape, and movement performance.

Key words: Intrinsic flexor muscles of the foot, Muscle training, Muscle strength

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INTRODUCTION

When performing exercise, humans generally assume a basic, erect, bipedal posture. In this posture, we engage in different movements at varying speeds, such as walking, running, kicking, and jumping. The feet are an important body component, as they constantly function as shock eliminators, weight support structures, and locomotive organs at any given time¹⁻⁹). In recent years, many reports have indicated that toe flexor strength and grip force training leads to significant changes in walking speed or pace and improved dynamic balance and prevents falls^{10, 11}). However, the common training methods for foot-related research, treatment, and prevention have typically included flat-footed exercises such as towel gathering or toe exercises. These exercises use extrinsic and intrinsic muscles without distinction, and many points regarding their frequency, load, implementation time, implementation period, and effects remain unclear. Furthermore, previous studies, including one conducted by our research team, have reported the importance of the intrinsic foot muscles, but the effects of such training have not been clarified¹²). If a training effect is acceptable, improvements in athletic performance, treatment of foot disease, long-term foot function maintenance, obstacle pre-

vention, enhancements in the standing and walking positions, and further exercise of a flat feet loads are expected.

The purpose of the present study was to focus on the intrinsic foot flexor muscles, and to verify the effects of a strength training method with fixed repetitions and loads on (1) muscle strength, (2) foot arch formation, and (3) dynamic test items (1-legged long jumping, vertical jumping, and 50-m dash time).

SUBJECTS AND METHODS

The subjects were 12 healthy males (12 left and 12 right feet) without motor system diseases or history of foot-related conditions such as flat feet (low arches). The mean (\pm standard deviation) age, height, and weight were 29 ± 5 years, 172.5 ± 7.3 cm, and 64.9 ± 12.8 kg, respectively. The subject characteristics are shown in Table 1. There is no sport history which continued the subject being tested in the period before and behind training, and it is not carrying out except this training. The test items were measured before (pre-training) and after 8 weeks of training (post-training), and the values were compared using statistical analysis.

A digital grip dynamometer (model# 5101, Takei Scientific Instruments Co., Ltd., Niigata, Japan) was used to measure intrinsic foot flexor strength and could display values ≥ 5 kg in increments of 0.1 kg. A wooden box was constructed for the dynamometer, measuring $50 \times 14 \times 60$ cm (length \times width \times height), which stabilized the device and lower limbs during the measurements.

The limbs were fixed with the subject in the supine position, with their knees in extension and the ankles in maxi-

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Table 1. Characteristics of the subjects

Subject being tested	Age (years)	Height (cm)	Height (cm)	Height (cm)
A	32	182	100	30.2
B	27	164	65	24.2
C	29	180	64	19.8
D	26	170	59.8	20.7
E	29	174	61	20.1
F	30	168	56	19.8
G	31	170	73	25.3
H	36	174.5	63	20.7
I	22	165	51	18.7
J	22	174	62	20.5
K	32	186	72	20.8
L	36	163	53	19.9

BMI: body mass index

num plantar flexion. Next, after correcting any distal interphalangeal (DIP) joint curvature caused by extrinsic muscle contraction resulting from passively flexing the toe, a Finger Sling (C7791, SAKAI Medical Co., Ltd., Tokyo, Japan) was used to flex each toe, with the dynamometer fixed at a 5-kg load.

The intrinsic foot flexor strength was quantified for all toes by measuring the flexion-gripping force in the interphalangeal (IP) and metatarsophalangeal (MP) joints. These measurements were performed with the subjects barefoot, and 3 measurements were performed for the left and right feet, which were then averaged for each foot. The muscle contraction time for each measurement was 3 s. The measurements were collected on a total of 3 days with the same testers, and were performed at a 2–3-day interval. The interobserver correlation (interclass correlation coefficient, 1.3) indicated a high reliability of 0.98 between testers for muscle strength measurement values. Therefore, these measurements were collected three times and the mean values of these 3 measurements were used.

For arch measurement, the longitudinal and horizontal arch lengths were recorded for the left and right feet to create a static standing position using a Berkemann footprint. The longitudinal arch length was defined as the distance from the head of the first metatarsal bone to the calcaneal tuberosity. The horizontal arch length was defined as the distance encompassing the head of the first metatarsal bone to the head of the fifth metatarsal bone. The dynamic test items were 1-legged long jumping, vertical jumping, and 50-m dash time. One-legged long jumping was evaluated on the basis of the measurement method used for the standing broad jump in the new physical strength test used by the Ministry of Education, Culture, Sports, Science and Technology, Japan. In this test, a tape measure was used to measure the distance from the toes to the heel of the measured lower limb. The measurements were collected twice for the left and right lower limbs, and the mean values for these measures were used.

Vertical jumping measurement values were displayed

numerically on a Jump MD measurement device (Takei Scientific Instruments Co., Ltd., Niigata, Japan), which can display measurements in 1-cm increments. Vertical jump measurements were collected twice, and their mean value was used.

For measuring the 50-m dash time, a start signal was used by the tester who announced the start time and bent their arm at the start line. Subjects started the 50-m dash from a standing position, and the tester used a stopwatch to time how long it took for the subject's torso to cross the finish line. Measurements were collected twice, and their mean value was used.

Subjects were positioned so that their hip joints were flexed at 90° angles. Then, similar to the other methods for measuring muscle strength, a barefoot toe IP and MP joint-flexing exercise was performed simultaneously with the left and right feet. This exercise was performed for 200 repetitions, once per day, three times per week with a 3-kg load that was set using scales with a maximum capacity of 10 kg (Sanko Seikohjyo Co., Ltd., Tokyo, Japan). Training was conducted over a period of 8 weeks. A metronome indicated the desired exercise rhythm until the subjects could independently maintain the rhythm. The subjects flexed their toes for 1 s before extending them to their resting position for 1 s, and this movement was performed repeatedly, thereby creating a rhythm of 1 repetition per 2 s.

The pre- and post-training measurement values are presented as mean \pm standard deviation values (mean \pm SD). A Wilcoxon signed-rank test was used to examine differences in the test results. A p-value of <0.05 was used to indicate statistical significance. SPSS version 14.0 (SPSS JAPAN Inc., Tokyo, Japan) was used for statistical analysis.

The ethics committee of Juntendo University Graduate School of Health and Sports Science approved this study (no. 21-34). All subjects were given an explanation of the objectives and content of the study before they provided written consent.

RESULTS

The left and right intrinsic foot flexor strengths significantly increased ($p < 0.01$), and the left and right longitudinal arch lengths ($p < 0.01$) and horizontal arch lengths, measured from a static standing position ($p < 0.01$), significantly decreased after training compared with those before training (Table 2).

Additionally, the left and right 1-legged long jumping distances ($p < 0.01$) and the vertical jumping height ($p < 0.05$) significantly increased, and the 50-m dash time significantly decreased ($p < 0.01$) after training compared with those before training (Table 2).

DISCUSSION

In contrast to previous studies, we implemented a strength training program that focused on intrinsic foot muscle strength and excluded extrinsic foot muscle function as much as possible. With the ankle in plantar flexion, the extrinsic foot muscle origin and insertion points draw closer to each other, thereby lowering the flexion action

Table 2. Test item results

Inspected		Pre-training	Post-training
Toe grip (kg)	L	9.3 (5.6–11)	14.4 (11.9–15.5)**
	R	9.4 (6.2–12.7)	14.2 (12.1–15.7)**
Arch length (cm)	L	18.6 (17.3–20.1)	17.7 (17.2–19.4)**
	R	18.7 (17.9–19.6)	18.1 (16.7–19)**
Transverse arch length (cm)	L	10.4 (9.7–11.3)	10.1 (9.5–10.7)**
	R	10.3 (10–11.1)	10.1 (9.8–11)**
Long jump with one leg standing (cm)	L	178.8 (163.5–217)	198.3 (177–226.5)**
	R	179 (151.5–206)	189.5 (166.5–227)**
Vertical jump (cm)		54 (43.5–71.5)	55.5 (49.5–73)*
50-meter dash time (s)		7.34 (6.79–8.58)	7.05 (6.5–8.22)**

**p<0.01; *p<0.05.

and becoming more dependent on the intrinsic foot muscles. This led Hayashi et al.¹²⁾ to establish a DIP joint flexion measurement method, so that the intrinsic foot muscle strength contributed to almost 100% of the proximal IP (PIP) and MP joint flexion. The present study implemented training and muscle strength measurements specialized for the intrinsic foot flexor muscles with the gripping force of all of the toes.

In order to measure intrinsic foot flexor strength, we created an original strength measurement device because no commercially available device exists. As the test–retest method indicated reproducibility without observable differences and high interobserver correlation, the measurement device used in this study is sufficiently reliable.

Statistically significant differences were found for each measurement test item when the pre- and post-training scores were compared. That is, we observed an increased intrinsic foot flexor strength, shorter longitudinal and horizontal foot arches, greater 1-legged long jumping distances, greater vertical jumping heights, and shorter 50-m dash times.

Increased intrinsic foot flexor strength values were observed after training. Toe gripping force training has been reported to elicit positive results that can be observed after 3 weeks according to Fukuda et al.¹⁰⁾ or 4 weeks according to Usaba and Ihara^{13, 14)}. These findings are considered to be due to the influence of neurological elements. Because the results of the present study indicated that the training load was approximately 30% of the mean maximum strength for all subjects and increased strength scores were recorded for all subjects, it appears that these results were due to neurological rather than muscle adaptations (i.e., hypertrophy), as was indicated by previous studies. However, the details for such mechanisms remain unclear.

Foot-arch measurements revealed that the longitudinal and horizontal foot arches were shortened after training, which suggests arch formation. This finding also suggests that arch maintenance function improved along with increased intrinsic foot flexor strength scores. Ukai et al.¹⁵⁾ reported that forefoot arch maintenance is dependent on the intrinsic foot muscles, whereas Umeki et al.¹⁶⁾ reported that the arches are shortened by intrinsic and extrinsic foot muscle contraction during 1-legged standing, which protects the

plantar support ligaments and joint tissue. We believe the shortened arches observed in the present study were due to an increased intrinsic foot flexor strength, which made arch formation possible through muscle contraction.

Performance of all dynamic test items improved in the post-training period, with increased 1-legged long jump distances, greater vertical jumping heights, and shorter 50-m dash times. Rabita et al.¹⁷⁾ reported that the elements that improve jumping function are muscle tendon structure and intrinsic muscle hardness, although it is also important to take a neuromuscular function approach to training. This suggests that we were able to achieve increased foot hardness that was accompanied by an improved intrinsic foot flexor toe gripping strength and arch formation. Mann et al.¹⁸⁾ reported that when running at top speed, the intrinsic muscles are continuously bearing weight. Thus, we inferred that the volume of intrinsic foot flexor activity would improve under high-load conditions. In addition, running and jumping movements involve high loads and require plantar flexion position movements. The present training position was a toe flexion movement with the ankle positioned in maximum plantar flexion, and the necessary ankle plantar flexion position stability in the final exercise area, along with PIP and MP joint ejection power, was exhibited. We believe that this resulted in greater anterior propulsive force and jumping power, leading to improved performance.

Although it cannot be ignored that other factors relating to the joints and muscles, such as quadriceps activity, may have affected the results of the present study, we believe that reinforcement of the intrinsic foot flexor muscles should receive sufficient focus. Furthermore, we believe that intrinsic foot flexor strength training is useful for improving standing and walking performance, in addition to improving the performance of sports athletes engaged in activities involving greater exercise loads.

REFERENCES

- 1) Miyazaki K: Impact loading on the foot and ankle and its attenuation during level walking. *Kurume Med J*, 1998, 45: 75–80. [Medline] [CrossRef]
- 2) Dixon PC, Böhm H, Döderlein L: Ankle and midfoot kinetics during normal gait: a multi-segment approach. *J Biomech*, 2012, 45: 1011–1016. [Medline] [CrossRef]
- 3) Rouhani H, Favre J, Crevoisier X, et al.: Ambulatory measurement of

- ankle kinetics for clinical applications. *J Biomech*, 2011, 44: 2712–2718. [[Medline](#)] [[CrossRef](#)]
- 4) Lambrinudi C: Use and abuse of toes. *Postgrad Med J*, 1932, 8: 459–464. [[Medline](#)] [[CrossRef](#)]
 - 5) Hughes J, Clark P, Klenerman L: The importance of the toes in walking. *J Bone Joint Surg Br*, 1990, 72: 245–251. [[Medline](#)]
 - 6) Stokes IA, Hutton WC, Stott JR, et al.: Forces under the hallux valgus foot before and after surgery. *Clin Orthop Relat Res*, 1979, 142: 64–72. [[Medline](#)]
 - 7) Hutton WC, Dhanendran M: A study of the distribution of load under the normal foot during walking. *Int Orthop*, 1979, 3: 153–157. [[Medline](#)]
 - 8) Ctercteko GC, Dhanendran M, Hutton WC, et al.: Vertical forces acting on the feet of diabetic patients with neuropathic ulceration. *Br J Surg*, 1981, 68: 608–614. [[Medline](#)] [[CrossRef](#)]
 - 9) Lieberman DE, Venkadesan M, Werbel WA, et al.: Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*, 2010, 463: 531–535. [[Medline](#)] [[CrossRef](#)]
 - 10) Fukuda I, Kobayashi R: The effect of the toes-grip training in healthy young adults. *Phys Ther Jpn*, 2008, 35: 261–266.
 - 11) Kitou N, Ihara H, Miwa M, et al.: Effects of toe motion exercise to prevent falls in the elderly. *Phys Ther Jpn*, 2001, 28: 313–319.
 - 12) Hayashi N, Ukai T, Ootake N, et al.: The relationship between metatarsal arch and toe flexion strength. *Journal of the 8th Society for Rehabilitation of Orthopaedics Conference*, 2000, 6: 9–12.
 - 13) Usaba M, Nakayama M, Takayanagi K: The effects of increased toe flexion strength on gross muscle strength and dynamic movement. *Kyushu Sports Soc J*, 1994, 16: 81–85.
 - 14) Ihara H, Yoshida T, Takayanagi K, et al.: Effect of toe and sole training on muscle power, response and balance. *Jpn J Orthop Sports Med*, 1995, 15: 268.
 - 15) Ukai T, Hayashi N, Hashimoto T, et al.: Effect of taping on stride length. *Phys Ther Jpn*, 2000, 27: 217.
 - 16) Umeki Y: Static results of medial foot arch. *J Jpn Orthop Assoc*, 1991, 65: 41–51.
 - 17) Rabita G, Couturier A, Lambertz D: Influence of training background on the relationships between plantarflexor intrinsic stiffness and overall musculoskeletal stiffness during hopping. *Eur J Appl Physiol*, 2008, 103: 71–77.
 - 18) Mann RA, Hagy JL: The function of the toes in walking, jogging and running. *Clin Orthop Relat Res*, 1979, 142: 24–29. [[Medline](#)]