Title：Improvement in muscle strength with low-load isotonic training depends on fascicle length but not joint angle

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ABSTRACT

Introduction: This study investigates whether low-load isotonic training will elicit greater improvement in muscle strength at the same fascicle length, rather than at the same joint angle. **Methods:** 16 healthy men (24.1 ± 2.5 years) were randomly divided into intervention and control groups. The pre- and post-training, maximum isometric and isokinetic strengths, and the fascicle length of medial gastrocnemius muscle were measured. Isotonic resistance training at 15° to 30° ankle plantar flexion at low intensity was conducted for 4 weeks. **Results:** The maximum isometric and isokinetic strength of the intervention group increased significantly only at 15° dorsiflexion and 8° to 12° dorsiflexion. Fascicle length during maximum voluntary contraction at 15° to 0° dorsiflexion was similar to fascicle length under training conditions. **Discussion:** It is possible that the improvement in muscle strength with low-load training depends on fascicle length rather than joint angle.

Key words: Plantar flexion; Ultrasound; Triceps surae; Specificity of training; Training adaptation, Low-load

INTRODUCTION

Muscle strength is known to specifically improve at the applied angle of training. In isometric training, Kitai and Sale (1989)[1] reported that ankle plantar flexion training using maximum voluntary isometric contraction at an ankle angle of 0° (i.e., 90° angle between the tibia and the sole of the foot) produces an improvement in the maximum isometric strength at an ankle position of only around 0° (between −5° and 5°). These results demonstrate the so-called joint angle specificity on training effect [1]. Moreover, it was reported that the muscle strength specifically improves at the training angle used during not only isometric training but also isotonic and isokinetic training. Graves et al. (1989)[2] and Barak et al. (2004)[3] respectively examined the effect of isotonic and isokinetic high-load training of knee extension, and reported that the improvement in maximum isometric strength occurred at the training angle. On the other hand, some reports have demonstrated that an improvement in maximum muscle strength can be obtained over a wide range of joint angles around the training angle during isometric training [4-7] or eccentric isokinetic training [3]. Thus, because a consensus view regarding joint angle specificity has yet to be achieved, further research and investigation are required.

In general, it has been stated that a high load of more than 60% of maximum voluntary contraction is needed to gain an improvement in strength during resistance training [8]. Therefore, all previous studies investigating the joint angle specificity of the training effect used a high load of more than 70% maximum voluntary isometric contraction or 60% one repetition maximum (1RM).

However, our recent study[9] showed that isometric training with a low-intensity 30% maximum voluntary contraction was effective for improving the muscle strength at a different joint angle from the training angle. Our findings suggest that the effects of low-intensity training depend on not the joint angle specificity but on the fascicle length. The fascicle length is affected by both the joint angle and the contraction level. During high-load training, because the forces exerted during training are similar to those during the measurement of maximum isometric strength, the fascicle length during training will also be similar at the same joint angle used when measuring maximum strength. This suggests that it is uncertain whether the training effects depend on the joint angle or the fascicle length during high-load training. From the perspective of our previous study[9], during isotonic training, it can also be perceived that an improvement in muscle strength is affected by fascicle length, which is determined from the load and joint angle. However, the influence of the fascicle length on the improvement in muscle strength during low-load isotonic training is unclear.

The purpose of this study is to examine whether an improvement in muscle strength depends solely on the joint angle, or rather on the fascicle length, which is affected by the training load and joint angle, when applying low-load isotonic plantar flexion training. We hypothesized that low-load isotonic training will result in a greater improvement in muscle strength at the same fascicle length, rather than at the same joint angle used during training.

MATERIALS AND METHODS

Participants

16 healthy men (24.1 ± 2.5 years in age), non-athletes with no involvement in regular stretching or resistance training, participated in this study. Persons with a history of neuromuscular disease or musculoskeletal injury involving the lower limbs were excluded. The subjects were randomly assigned to an intervention group (n = 8) or a control group (n = 8) using a computerized random number function in Microsoft Excel. All subjects were fully informed of the procedures and purpose of the study, which conformed to the Declaration of Helsinki. Written informed consent was obtained from all subjects. This study was approved by the ethics committee of Kyoto University Graduate School and the Faculty of Medicine (R-0216).

Procedures

This was a randomized controlled trial. A flowchart of the experimental protocol is shown in Figure 1. Prior to the pre-training, all subjects were familiarized with the maximum voluntary contraction procedure for plantar flexion. During the initial week of the experiment, the subjects attended three familiarization sessions, practicing maximum voluntary isometric, isokinetic, and isotonic contractions. For the maximum voluntary isometric contractions, the subjects practiced the four ankle joint positions used for testing, set at 15° intervals over a range from 15° dorsiflexion to

30° plantar flexion. For the maximum voluntary isokinetic contractions, the subjects practiced at 20°/s over a range from 15° dorsiflexion to 30° plantar flexion. For the maximum voluntary isotonic contractions (1RM), the subjects practiced three ranges of ankle joint angle (15° dorsiflexion to 0°, 0° to 15° plantar flexion, and 15° plantar flexion to 30° plantar flexion). An ankle joint angle of 0° (neutral position) was defined as a 90° angle between the fibula and fifth metatarsal bone. Following the familiarization sessions, the muscle strength during maximum voluntary contraction of the ankle plantar flexors, the fascicle length, pennation angle, and muscle thickness were measured pre-training. The same measurements were conducted after 4 weeks of training, resulting in a total experimental period of five weeks.

Training protocol

The intervention group underwent isotonic resistance training of ankle plantar flexion at an intensity of 20% 1RM, 3 days per week for 4 weeks, using a Biodex dynamometer (Biodex System 4, Biodex Medical Systems, Inc., Shirley, New York, USA.). The isotonic resistance training protocol consisted of 3 sets of 20 repetitions of plantar flexion contraction of only the concentric phase, performed at 15° to 30° plantar flexion, with a 1-s rest between each contraction, and a 2-min rest between sets. Isotonic training was conducted at a speed of 5°/s over an ankle angle range of 15° to 30° resulting in a 3-s movement per repetition. The subjects were instructed to maintain a fixed velocity on the dynamometer using a metronome. An examiner supervised all training sessions and checked whether the subjects were able to exert force at the proper speed. The subjects in the control group did not receive any intervention.

Procedure of muscle strength measurement

The muscle strength of each subject was determined by measuring the maximum voluntary isometric strength, maximum isokinetic voluntary isokinetic strength, and 1RM using a Biodex dynamometer with a sampling rate of 1000 Hz. For each measurement, the ankle joint of the dominant leg was securely attached to the footplate of the dynamometer using a velcro strap. A soft cloth was inserted between the velcro strap and the instep to prevent any unwanted movement of the ankle joint. The trunk and distal thigh were securely fixed using dynamometer belts to keep the hip joint position at an 80° flexion and the knee joint at full extension. The subjects grasped the horizontal bars attached to the dynamometer. Before each test, the subjects underwent a warm up of 10 to 20 submaximal isometric contractions. After more than 1 min of rest, the subjects were asked to generate their maximum voluntary isometric and isokinetic contractions in random order. The measurement of their 1RM was obtained last because it caused significant fatigue. Total measurement time was about 60 min.

The maximum isometric strength was measured at four ankle positions (see above), with the order of maximum voluntary isometric contraction randomized across the participants. Their maximum voluntary isometric contraction was exerted for 5 s at each of the four ankle joint angles, with more than 2 min of rest provided between each maximum voluntary isometric contraction. Their maximum isometric strength was measured twice at each ankle joint angle, and the greater value of the two measures was used for the analysis.

The maximum voluntary isokinetic contraction was conducted twice at 20°/s with more than 2 min of rest between trials. Their isokinetic strength was measured at every 1° across the range of 15° dorsiflexion to 30° plantar flexion. Their maximum isokinetic strength was determined to have the highest value of isokinetic strength. The greater value of two measurements was used for the analysis. Moreover, their isokinetic strength measured every 1° across the range of 15° dorsiflexion to 30° plantar flexion was also used for analysis.

The 1RM was measured at 3 ranges of ankle joint angle in random order. The load was started from the 1RM value during the familiarization session, and increased by 5 to 10 Nm until the subject was unable to apply the required full range of plantarflex motion, at which time the load was decreased by 5 Nm. The last acceptable plantar flexion with the highest possible load was determined as 1RM. A rest period was allotted between each attempt to ensure recovery.

Measurements of fascicle length, pennation angle, and muscle thickness

The fascicle length and pennation angle of the medial gastrocnemius (MG) were measured at proximal 30% of the lower leg length [10], using B-mode ultrasound imaging (LOGIQ e, General Electric, Duluth, GA, USA) with an 8-MHz linear array probe (6 cm) with a gain of 58 to 70 dB. The depth and dynamic focus settings of the equipment were controlled to achieve a clear image of the MG. The fascicle length was measured under isotonic training conditions (at 15° to 30° plantar flexion with 20% 1RM) and during muscle strength measurements pre- and post-training. In the measurement of ultrasound imaging at maximum isometric strength, the images were preserved when the exerted force displayed on the dynamometer monitor reached a plateau. The images during isokinetic strength measurements and under isotonic training conditions were measured using the moving imaging function. A static sonographic image was gained at each 2° of plantar flexion because the speed of the dynamometer was 20°/s and the image was recorded every 0.1 s.

The methods of measurement of the fascicle length and pennation angle are shown in Figure 2. The fascicle length was estimated from these images based on the methods used to evaluate the distance along a straight line, between the extension lines from the aponeurosis, and the origin of the fascicle as previously described for the quadriceps muscle[11-14]. The reliability of this method for the measurements of the MG was shown in our previous study [9]. The intraclass correlation coefficient (ICC 1.1) for the fascicle length of the MG was showed good reliability for both the inter session (ICC > 0.9) and inter day (ICC > 0.75)[11]. The pennation angle was defined as an angle of the fascicle and deep aponeurosis. The fascicle length and pennation angle were measured under each condition using image processing software (ImageJ, version 1.48, National Institutes of Health, Bethesda, MD, USA).

To examine the morphological changes, the fascicle length, the pennation angle, and the muscle thickness of the MG, lateral gastrocnemius (LG), and soleus (SOL) at rest with an ankle position of 0° were measured pre- and post-training in the proximal 30% of the lower leg. The muscle thickness was measured to assess whether the improvement in muscle strength was due to muscle hypertrophy, by measuring the line drawn perpendicular from the surface to the deep aponeurosis along the transverse plane. To accurately measure the muscle thickness without including non-contractile tissue, measurements between the inside edges of the aponeurosis were used. Previous studies showed reliability of the ultrasound technique for measuring the muscle thickness of the triceps surae [12,13].

Statistical analysis

Statistical analysis was conducted using SPSS (version 22.0, IBM Japan Inc., Tokyo, Japan). The normality of the data was evaluated using a Shapiro-Wilk test. Group differences regarding the characteristics and maximum muscle strength at the baseline were assessed using an unpaired t-test.

A split-plot ANOVA with two factors (group × time) was used to analyze the effects on the maximum muscle strength, the fascicle length, the pennation angle, and muscle thickness. A two-way repeated measures ANOVA with two factors (ankle joint angle × time) was used to determine the differences in isokinetic strength. A paired t-test was used to determine significant differences between the value pre- and post-training when significant interactions or main effects were found.

The paired t-test was used to determine the differences in fascicle length between isotonic training conditions (at 15° to 30° plantar flexion with 20% 1RM) and during muscle strength measurements at each angle in the intervention group in post-training. The fascicle length under the training conditions was calculated as the mean value at 15° to 30° plantar flexion in pre- and post-training. The differences were considered to be statistically significant at an alpha level of 0.05.

RESULTS

None of the subjects dropped out, and all subjects in the intervention group completed the training sessions. There were no significant differences in age, height, or body mass between the intervention group (23.0 ± 1.1 years, 174.0 ±7.0 cm, 70.3 ± 8.2 kg) and control group (25.2 ± 3.0 years, 171.1 ± 3.4 cm, 63.0 ± 6.8 kg). There were also no significant differences in any variables of their maximum muscle strength at the baseline between the two groups.

Effects of isotonic training intervention on maximum muscle strength

Maximum muscle strength pre- and post-training is shown in Table 1.

The split-plot ANOVA, using two factors (group × time), showed no significant interaction at any ankle angle. Main effects for time were significant at 15° dorsiflexion ($p = 0.02$), but were not significant at 0°, 15°, and 30° plantar flexion. At 15° dorsiflexion, the maximum isometric strength post-training was significantly higher than pre-training in the intervention group ($p = 0.03$), but there was no significant change in the control group.

The split-plot ANOVA, using two factors (group × time), showed no significant interactions or a main effect of maximum isokinetic strength and 1RM at any range of ankle angle between pre- and post-training in both groups.

The changes in isokinetic strength over a range of ankle angles from 15° dorsiflexion to 30° plantar flexion are shown in Figure 3. Two-way repeated measures ANOVA (ankle joint angle × time) showed a significant interaction in the intervention group. There were significant increases in isokinetic strength at 12° to 8° dorsiflexion. However, there were no significant differences in the control group.

Differences in fascicle length between under isotonic training conditions and during muscle strength measurements

In the intervention group, the mean value of the fascicle length under the training conditions was 3.54 ± 0.64cm.

The fascicle length during maximum isometric strength measurements post-training for the intervention group at 15° dorsiflexion was 3.71 ± 1.03 cm, and that for the group at 0°, 15°, and 30° plantar flexion were 3.18 ± 0.82 cm, 2.72 ± 0.67 cm, and 2.42 ± 0.50 cm, respectively. There were significant differences in the fascicle length between the training conditions and maximum isometric contraction at 15° and 30° plantar flexion. However, there were no significant differences between the training conditions and maximum isometric contraction at 15° dorsiflexion and at 0°.

The fascicle length during the maximum isokinetic strength measurement within a range of ankle angle from 15° dorsiflexion to 30° plantar flexion is showed in Figure 4. There were no significant differences in the fascicle length between the training conditions and the isokinetic strength measurements between 5° and 1° dorsiflexion.

Effects of intervention on fascicle length, pennation angle, and muscle thickness

The results of changes in fascicle length, pennation angle, and muscle thickness at rest with an ankle position of 0° are shown in Table 2. No significant differences were found in fascicle length, pennation angle, or muscle thickness between pre- and post-training in either group. Moreover, no significant differences were found in fascicle length or pennation angle during maximum muscle strength measurement between pre- and post-training (see Table 3).

DISCUSSION

The results of this study show that isotonic training with 20% 1RM at an ankle angle of 15° to 30° plantar flexion resulted in a significant improvement in maximum isometric strength at 15° dorsiflexion, and isokinetic strength at 8° to 12° dorsiflexion.

Our results show that there was a significant improvement in maximum isometric strength at 15° dorsiflexion in only the intervention group, though they received isotonic training at ankle angles of 15° to 30° plantar flexion. That is, there was no significant change in isometric strength at the training angle. This result is inconsistent with the joint angle specificity of the training effect as proposed for isometric[1] and isotonic[2] training. Our previous study [9] reported that the improvement of muscle strength in isometric training depended on fascicle length rather than joint angle. In this study, there was no significant difference in fascicle length during low-load training at 15° to 30° plantar flexion (3.54 ± 0.64 cm) and the measurement of maximum isometric strength at 15° dorsiflexion (3.71 ± 1.03 cm). This result implies that the fascicle length during training was similar to that of maximum voluntary isometric contraction regardless of the different ankle angles applied. Our findings suggest that low-load isotonic training may be effective for improving the maximum isometric strength not at the same joint angle but at the same fascicle length during training, and that the effects of low-load isotonic training with a shortened fascicle length can be produced at a more lengthened fascicle position.

Our results also show that isokinetic strength improved significantly only within the range of 12° to 8° dorsiflexion, without a significant increase in maximum isokinetic strength. This result suggests that there was an improvement in muscle strength specifically within the range of 12° to 8° dorsiflexion, which was not influenced from the improvement of the maximum voluntary isokinetic contraction. Similar to the result of the maximum isometric strength, the result of the isokinetic strength was also inconsistent with the joint angle specificity of the training effect. The fascicle length at 5° to 0° dorsiflexion of the maximum isokinetic contraction was almost the same as the fascicle length during training. Unfortunately, the results of our study are inconsistent with our hypothesis that an improvement in muscle strength depends on the fascicle length during training, because the isokinetic strength improved within the range of 12° to 8° dorsiflexion. The discrepancy may be due to a lack of perfect synchronization between a dynamometer and ultrasound imaging. In this study, the initial movement of the dynamometer and the initial muscle contraction in the ultrasound imaging were synchronized manually. If the muscle contraction occurs before the movement of dynamometer, the data on the fascicle length in the ultrasound imaging and the joint angle do not match. An inadequate synchronization might be the reason for the lack of improvement in isokinetic strength at the same fascicle length. Further investigation of the fascicle length through proper synchronization between the dynamometer and ultrasound imaging is needed.

There were no significant changes in 1RM at all the tested ranges of the ankle angle. 1RM reflects the weakest strength within each angle range. Generally, plantar flexion strength decreases with shortened fascicle length, which is seen at an angle with greater plantar flexion. Therefore, it is possible that the 1RM of the ankle angle from 15° dorsiflexion to 0°, from 0° to 15° plantar flexion, and from 15° to 30° plantar flexion were influenced by the maximum muscle strength at 0°, 15°, and 30° plantar flexion, respectively. In fact, the present study shows that there were no significant improvements in maximum isometric strength at 0°, 15°, and 30° plantar flexion, although there was a significant improvement in the maximum isometric strength at 15° dorsiflexion. Although it is speculative, the absence of improvement in isometric strength at 0°, 15°, and 30° plantar flexion may explain the reason for the absence in improvement of 1RM from 15° dorsiflexion to 0°, from 0° to 15° plantar flexion, and from 15° to 30° plantar flexion.

In this study, there were no significant differences in the fascicle length, the pennation angle, or the muscle thickness between pre- and post-training, suggestingthat the improvement in muscle strength was not caused by morphological changes but by neural adaptations. However, we could not measure the moment arm of triceps surae muscles. It was assumed that the moment arm of triceps surae muscles would be longer if muscle hypertrophy occurred because the moment arm becomes longer by the muscle bulge when the plantarflexor muscles contract[14]. In this study, it was assumed that the moment arm of triceps surae did not change because muscle thickness did not change after the training. The measurement of moment arm of triceps surae could be explored in the future.

As a limitation of this study, we did not investigate the effects of neural adaptation. Improvement in muscle strength after resistance training depends on neural adaptations over the initial period of training (<4 weeks), followed by morphological muscle adaptations after 6 to 8 weeks, which mainly contribute to the strength gains [15,16]. Our results show no changes in morphological measurements such as the fascicle length, the pennation angle, and the muscle thickness after training. Therefore, the improvement in maximum muscle strength after the 4-week intervention applied in this study may be influenced by neural adaptations, such as increases in the muscle activity of the agonist muscles and decreases in antagonist co-activation [17]. However, we did not measure the muscle activity because it may not be appropriate to compare muscle activity during maximum strength measurements between pre- and post- training, which were normalized with respect to the maximum voluntary contraction measured on different days. Further investigation is necessary to clarify the interactions between the neural adaptation mechanisms and the effects of specificity in the fascicle length during training. A second limitation of this study was the small sample size, which might cause an unclear interpretation of the relationship between the maximum isometric strength and the fascicle length. In fact, with regard to the changes in the maximum isometric strength at 0° of dorsiflexion, there was no significant improvement after training. Moreover, with regard to isokinetic strength, our hypothesis was also not clearly established because of inadequate synchronization between the dynamometer and ultrasound measurements. Therefore, our hypothesis of the specificity of fascicle length may not be supported completely in this study. The last limitation was that our study considered the fascicle length only for the MG because the reliability of the fascicle length measurements at various ankle joint angles and contraction levels is only certain for the MG muscle[9]. Therefore, the influence of other plantar flexor muscles such as SOL and LG on improvements in muscle strength is unclear.

The results of the present study show that low-load isotonic training with a shortened fascicle length improves isometric and isokinetic strength at different angles from angles used during training. The results suggest that the effects of the improvement in muscle strength may depend on fascicle length rather than joint angle during isotonic training. Thus, low-load training with a shortened fascicle length could improve muscle strength at a more muscle-lengthened position than the training position. It is possible that low-load training at a shortened muscle length may be more suitable and safer for persons unable to perform high-load training, or for patients who have a restricted range of joint motions.

Abbreviations:

1RM－one repetition maximum

MG－medial gastrocnemius

ICC－intraclass correlation coefficient

SOL－soleus

LG－lateral gastrocnemius

SD－standard deviation

DF－dorsiflexion

PF－plantar flexion

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Table 1 Effects of intervention on maximum muscle strength (Nm)

	intervention group (n = 8)		**control group (n = 8)**		**F value**	
	Pre-training	**Post-training**	**Pre-training**	**Post-training**	**Interaction**	**Main effect**
Maximum isometric strength						
DF15°	195.11 ± 42.92	206.89 ± 36.60*	207.31 ± 52.07	219.53 ± 47.36	F < 0.1	F = 7.48*
0°	167.24 ± 30.25	176.35 ± 28.02	177.65 ± 45.78	174.81 ± 38.44	F = 2.12	F = 0.59
PF 15°	127.29 ± 26.49	126.51 ± 23.22	123.60 ± 33.58	120.39 ± 30.23	F = 0.22	F = 0.60
PF 30°	78.53 ± 21.37	79.48 ± 24.05	75.54 ± 28.80	72.84 ± 25.13	F = 0.90	F = 0.21
Maximum isokinetic strength						
	140.16 ± 20.35	146.43 ± 26.76	161.16 ± 45.81	160.96 ± 42.36	F = 0.55	F = 0.49
1RM						
DF15° to 0°	189.38 ± 33.85	195.00 ± 23.45	191.25 ± 38.98	192.50 ± 34.95	F = 0.87	F = 0.17
0° to PF15°	146.88 ± 31.50	151.25 ± 31.14	146.88 ± 31.05	146.25 ± 33.25	F = 0.18	F = 0.31
PF15° to 30°	103.13 ± 27.64	100.00 ± 22.99	99.38 ± 26.52	98.13 ± 28.90	F = 0.46	F = 0.10

Values are expressed as mean ± SD (standard deviation)

DF = dorsiflexion, PF = plantar flexion

F value are showed for interaction (group × time) and main effect (time) in sprit plot ANOVA.

* significant difference between pre- and post-training (*P*<0.05)

Table 2 Effects of intervention on fascicle length, muscle thickness, and pennation angle

		Fascicle length（cm）		**Pennation angle（°）**		**Muscle thickness（cm）**	
		Pre-training	**Post-training**	**Pre-training**	**Post-training**	**Pre-training**	**Post-training**
MG	**IG**	5.93 ± 1.29	6.26 ± 1.08	24.39 ± 5.45	21.45 ± 1.61	2.25 ± 0.82	2.02 ± 0.34
	CG	6.31 ± 1.35	6.49 ± 1.45	22.84 ± 2.99	23.77 ± 1.97	2.13 ± 0.45	2.12 ± 0.61
LG	**IG**	7.29 ± 1.75	6.81 ± 1.77	17.92 ± 1.78	18.62 ± 3.99	1.67 ± 0.24	1.63 ± 0.38
	CG	7.84 ± 1.88	7.92 ± 2.46	16.94 ± 3.40	18.99 ± 3.77	1.70 ± 0.44	1.78 ± 0.41
SOL	**IG**	4.49 ± 0.86	4.21 ± 1.13	20.16 ± 1.47	20.31 ± 5.61	1.69 ± 0.57	1.69 ± 0.46
	CG	5.06 ± 1.90	4.97 ± 1.27	19.75 ± 7.84	20.66 ± 5.55	1.73 ± 0.50	1.80 ± 0.52

Values are expressed as mean ± SD (standard deviation)

MG = medial gastrocnemius, LG = lateral gastrocnemius, SOL = soleus

IG = intervention group, CG = control group

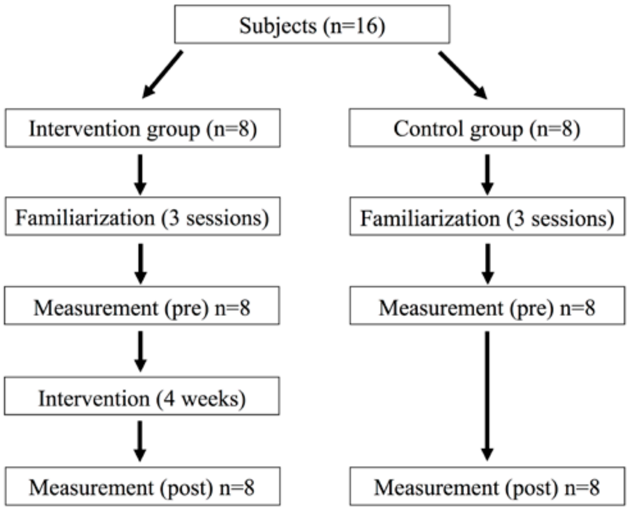
Table 3 Fascicle length and pennation angle at maximum isometric strength measurement

	Fascicle length（cm）				**Pennation angle（°）**			
	intervention group (n = 8)		**control group (n = 8)**		**intervention group (n = 8)**		**control group (n = 8)**	
	Pre-training	**Post-training**	**Pre-training**	**Post-training**	**Pre-training**	**Post-training**	**Pre-training**	**Post-training**
DF15°	3.96 ± 1.24	3.71 ± 1.03	3.87 ± 1.12	3.48 ± 0.86	32.88 ± 8.27	32.60 ± 6.88	33.48 ± 7.73	34.99 ± 6.26
0°	3.22 ± 0.93	3.18 ± 0.82	3.23 ± 1.04	3.09 ± 0.73	36.94 ± 9.43	38.02 ± 8.38	37.98 ± 9.23	41.48 ± 8.69
PF 15°	2.72 ± 0.77	2.72 ± 0.67	2.79 ± 0.69	2.93 ± 0.69	42.48 ± 9.24	43.44 ± 6.43	42.77 ± 8.09	42.68 ± 7.49
PF 30°	2.50 ± 0.60	2.43 ± 0.50	2.57 ± 0.65	2.62 ± 0.53	46.45 ± 8.91	49.73 ± 5.30	47.79 ± 11.99	46.57 ± 8.89

Values are expressed as mean ± SD (standard deviation)

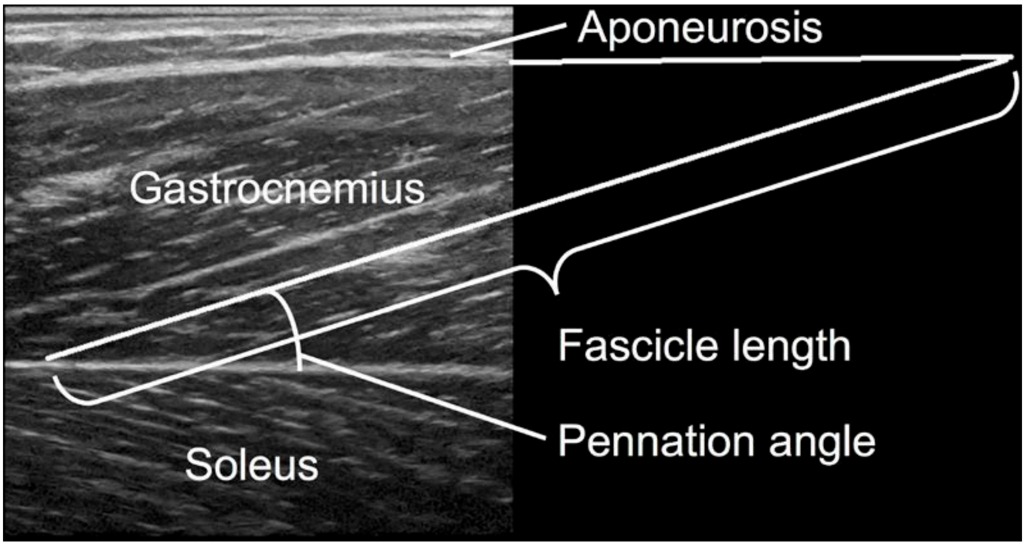
DF = dorsiflexion, PF = plantar flexion

Fig. 1 Flowchart of the present study.



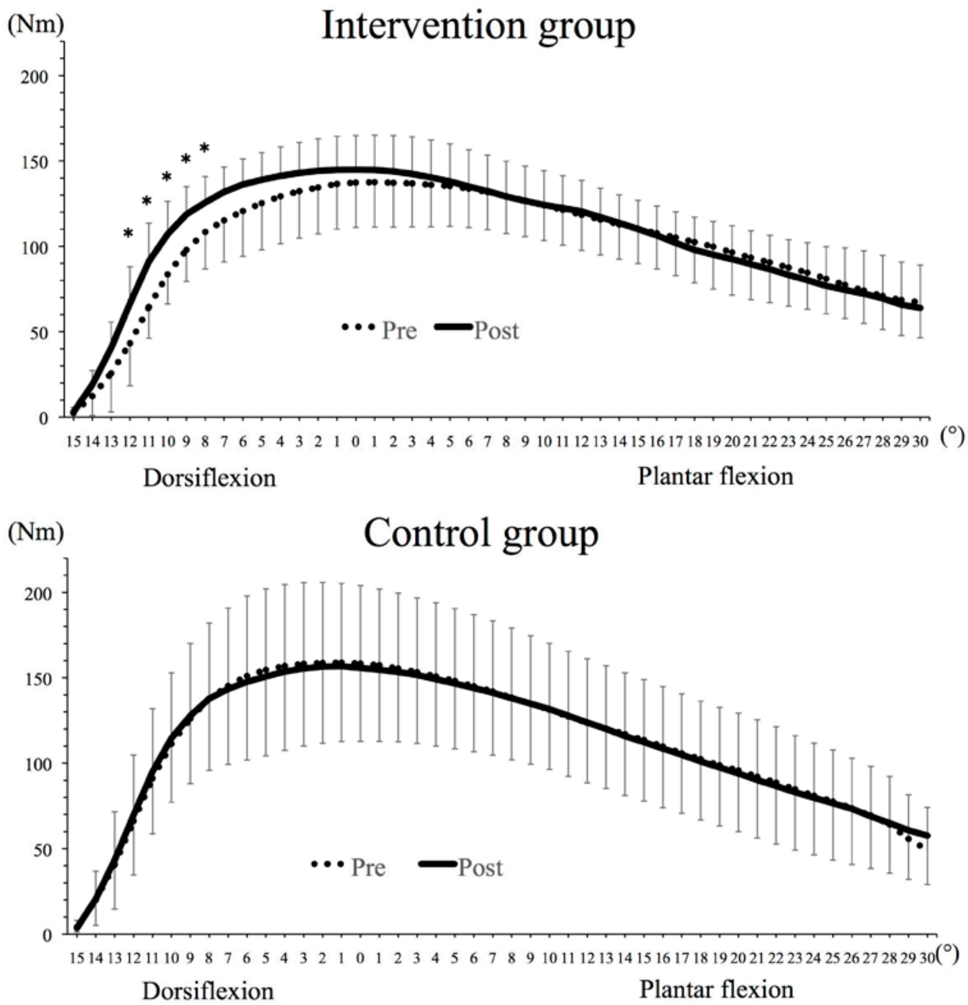
pre = pre-training, post = post-training

Fig. 2 Estimation of fascicle length.



The fascicle length of the medial gastrocnemius muscle was defined as the distance in a straight line between the extension lines from the aponeurosis and the fascicle origin.

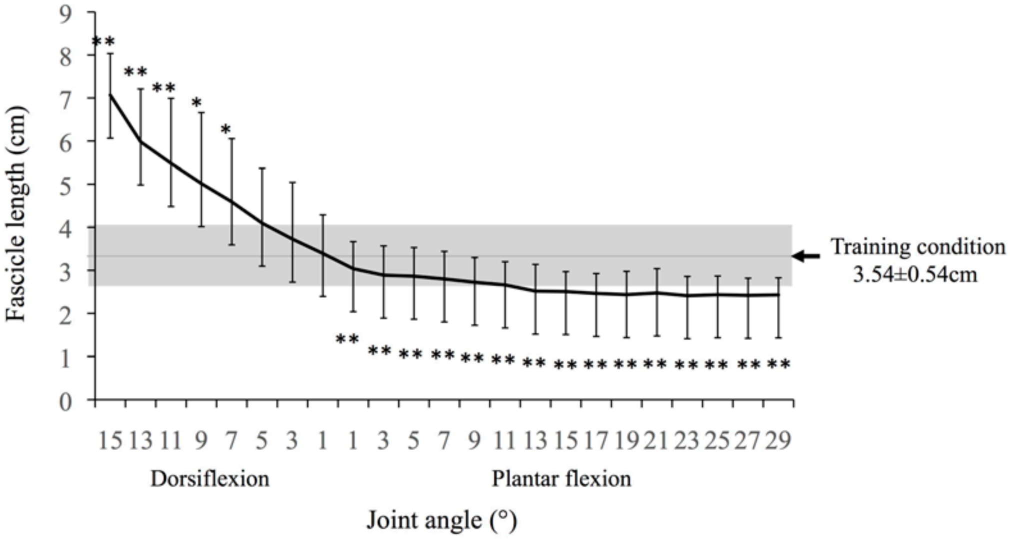
Fig. 3 Change in isokinetic strength at each ankle angle between pre- and post-training.



* indicates significant difference between pre- and post-training (P<0.05).

pre = pre-training, post = post-training

Fig. 4 Differences in fascicle length between isotonic training conditions and during maximum isokinetic strength measurements.



* indicates significant difference from the fascicle length under training condition (**$P<0.01$, *$P<0.05$).

The line indicated by the arrowlabeled “Training condition” shows the mean value of the fascicle length during isotonic training. The gray area shows the standard deviation of the value of the fascicle length during training.