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Original article

Effect of isokinetic resistance training under a condition of restricted blood flow with pressure

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Abstract

Background. The purpose of the present study was to investigate the effect of isokinetic training under the condition of restricted blood flow with pressure.

Methods. The subjects were 21 athletes at a university. They were classified into four training groups: group A (high speed under restricted blood flow condition with pressure); group B (low speed under restricted blood flow condition with pressure); group C (high speed without restricted blood flow condition); group D (low speed without restricted blood flow condition). The training session consisted of three sets of knee extension and flexion (repeated 10 times) using an isokinetic training machine (Biodex system 3). The training period was 4 weeks, with regular training sessions twice a week during this period. Before and after the training period, all of the subjects underwent measurements of quadriceps muscular strength of concentric contraction (CC) and eccentric contraction (EC) after isokinetic contraction as well as measurement of the thigh diameter. In addition, the group with restricted blood flow with pressure underwent magnetic resonance imaging (MRI).

Results. In regard to quadriceps muscular strength before and after training, there was a significant difference between groups A and C at many degrees of velocity. For the muscular volume measurements by MRI before and after training, no significant difference was seen in group A or group B. A significant increase was not seen even when comparing groups A and B.

Conclusions. Isokinetic resistance training with restricted blood flow with pressure had an effect on muscular strength improvement.

Introduction

Training to augment muscular strength is important for improving athletic prowess,[1] recovery and rehabilitation from injuries, and health improvement for the middle-aged and the elderly.[2] It has been said that resistance training conducted under high intensity contributes to improving one's muscular strength and muscular hypertrophy.[3] It has been pointed out, however, that for those undergoing rehabilitation immediately after an injury or for elderly individuals with advanced muscular atrophy, resistance training may incur a risk of exerting adverse effects on joints and blood pressure instead of increasing muscular strength.[4]

To reduce such risks, studies have recently been reported on "resistance training under restricted blood flow," which improves muscle strength at low intensity.[5–10] "Resistance training under restricted blood flow" is defined as that conducted while the base of an extremity is compressed to restrict blood flow to muscles: this procedure is believed to bring about a training effect at a very low intensity.[5]

A number of studies have proven the positive effect of isokinetic resistance training.[11–14] By artificially setting the exercise velocity, this training method enables a maximum load to be applied to the muscles at each joint angle.[11,13,14] In the current study, a safe, highly effective method for resistance training was evaluated by comparing the effects of isokinetic resistance training, in particular under restricted blood flow, at low and high velocities.

Subjects and methods

The subjects were 21 male students at a university who belonged to the track and field team, regularly engaged in daily exercises, and were free of injuries and diseases. The current experiment was explained, and informed consent according to the approval of the ethics committee was obtained from the subjects.

The means and standard deviations of age, body height, and body weight of the subjects were stratified by group and are shown in Table 1.

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Table1. Physical characteristics of the subjects

Training group	No.	Age (years)	Height		Weight	
			Centimeters	Feet	Kilograms	Pounds
A	6	20.0 ± 0.7	172.2 ± 1.8	5.65 ± 0.06	66.0 ± 1.3	145.2 ± 2.8
B	4	19.0 ± 0.5	172.8 ± 6.9	5.70 ± 0.20	65.3 ± 8.6	143.6 ± 19.0
C	6	19.9 ± 0.8	178.6 ± 5.4	5.86 ± 0.18	66.8 ± 5.6	147.0 ± 11.4
D	5	20.5 ± 1.0	172.8 ± 5.1	5.67 ± 0.17	65.6 ± 5.9	144.3 ± 13.0
All subjects	21	19.9 ± 0.6	174.1 ± 3.0	5.77 ± 0.10	65.9 ± 0.7	146.6 ± 1.5

Results are the mean ± SD

Isokinetic resistance training

Using the Biodex system 3 (Biodex Medical Systems, Shirley, NY, USA), hereafter abbreviated to Biodex, a device for isokinetic resistance training, the subjects underwent training with isokinetic knee extension and flexion that consisted of three sets of repeated extension and flexion of the knee joint, repeated 10 times, with a 60-s rest between sets. Each training session, conducted twice a week for 4 weeks, took about 15 min. We selected this training plan based on the advice of an athletic training coach and reports on the subject.

The test subjects were divided into four groups. All of the subjects in this study were sprinters who belonged to the track and field club at the same university, and the training was conducted as usual during the experimental period. The training was conducted 5 days a week for 2–3 h at a time. There was no difference in the frequency, amount of time, or contents of the training among the subject groups.

The training conditions were as follows.

- Group A ($n = 6$): The load (angular velocity) was set at 300°/s. During the training, a belt designed for resistance training under blood flow restriction was wrapped around the base of the thigh with an application of 200 mmHg pressure.
- Group B ($n = 4$): The load (angular velocity) was set at 90°/s. During the training, a belt designed for resistance training under blood flow restriction was wrapped around the base of the thigh, and a pressure of 200 mmHg was applied.
- Group C ($n = 6$): The load (angular velocity) was set at 300°/s. No blood flow restriction was applied.
- Group D ($n = 5$): The load (angular velocity) was set at 90°/s. No blood flow restriction was applied.

We select 200 mmHg pressure to the thigh as the blood flow restriction, as in other reports. At the pretest interview about added pressure, the subjects sometimes complained of moderate thigh pain during training under 250 mmHg pressure. However, they complained of no pain or very slight pain under 200 mmHg; hence, we selected the grade of blood flow to be 200 mmHg.

Measurement of knee extensor muscular strength

Before and after muscle resistance training, the knee extensor muscular strength was measured isokinetically and isometrically while the subject was in a sitting position using Biodex, an isokinetic muscle resistance measuring device. Each test result was obtained under angular velocities of 60°, 180°, and 300°/s for concentric contraction (CC) and 60° and 180°/s for eccentric contraction (EC). For isometric contraction (IM), the determination was made with the joint angle set at 60°/s flexion. For CC and EC, extension and flexion were measured at each angular velocity three to five times continuously; the reading with the largest torque was designated the peak torque (PT). IM was determined with flexion and extension, each conducted once. In view of individual differences in muscular strength, the peak torque per unit body weight (PT/BW), with the results in foot-pounds. For comparisons between the groups undergoing training, we used the percentage increases before and after the muscular strength was computed.

MRI test and computation of femoral muscle volume

To find the changes in the muscle volume before and after resistance training, the femoral cross section was photographed using MRI only for the groups with blood flow restriction (groups A and B). For MRI, Visart EX (Toshiba Medical, Tokyo, Japan) was employed with 1.5 T to produce a T1-weighted image. From the cross-sectional MRI image, a cross-sectional area was computed using Digitizer KD4600 (Graphtec, Tokyo, Japan). The result was indicated in its ratio to the cross-sectional area of the femoral bone. The determination was made 16 cm proximal from the upper end of the patella.

Statistical analysis

To analyze statistically within-group differences before and after training of muscle strength, we performed a paired Student's *t*-test. We also performed the post hoc test (Scheffe's F) for a multiple comparison after the two-factor factorial analysis of variance (ANOVA) as a statistical analysis of within-group differences. The level of significance was <5%. All of the data were expressed as the mean ± SD.

Results

We compared the muscular strength before training among the subject groups. The muscular strengths of the groups were as follows: group A 98.7 ± 17.9 U; group B 92.4 ± 12.6 U; group C 117.5 ± 18.7 U; group D 97.9 ± 14.9 U under the condition of CC 60°/s. The subjects in all four groups had equal muscle strength before training started.

No subject suffered any notable injuries during this resistance training under restricted blood flow with pressure.

Knee extensor muscular strength

Before and after resistance training

The results for knee extensor muscular strength are shown in Figs. 1–4. For PT/BW, group A showed a significant increase with angular velocities of 60° and 300°/s for CC and 60° and 180°/s for EC ($P < 0.05$). Group B also showed a significant increase at angular velocities of 60° and 180°/s for CC ($P < 0.05$). Group C showed a significant difference only at an angular velocity at 180°/s for CC ($P < 0.05$). Group D showed a significant difference at angular velocities of 180° and 300°/s for CC ($P < 0.05$).

Comparisons by percentage increase

Figures 5 and 6 show the percentage increase in knee extensor muscular strength for each group. In a comparison of groups A and C (both of which underwent resistance training at high velocity but group A also had blood flow restriction under pressure), there were significant increases with an angular velocity of 300°/s for CC and 60°/s for EC ($P < 0.05$) (Fig. 5). In a comparison of groups B and D (Fig. 6), both having undergone resistance training at low velocity, no significant differences were noted at any angular velocity.

For groups A and B, both having undergone resistance training with blood flow restriction under pressure, no significant differences were noted at any angular velocity. When a comparison was made between groups C and D, both having undergone resistance training without a blood flow restriction, the latter (with low-velocity training) showed a significant percentage increase at angular velocities of 180° and 300°/s for CC ($P < 0.05$).

Figure 7 shows percentage increases in groups A and B with blood flow restriction and groups C and D without blood flow restriction. When the groups with a restricted blood flow were compared against those without, the percentage increase was greater at all angular velocities in the groups with the blood flow restriction, but a significant difference was noted only at an angular velocity of 300°/s ($P < 0.05$).

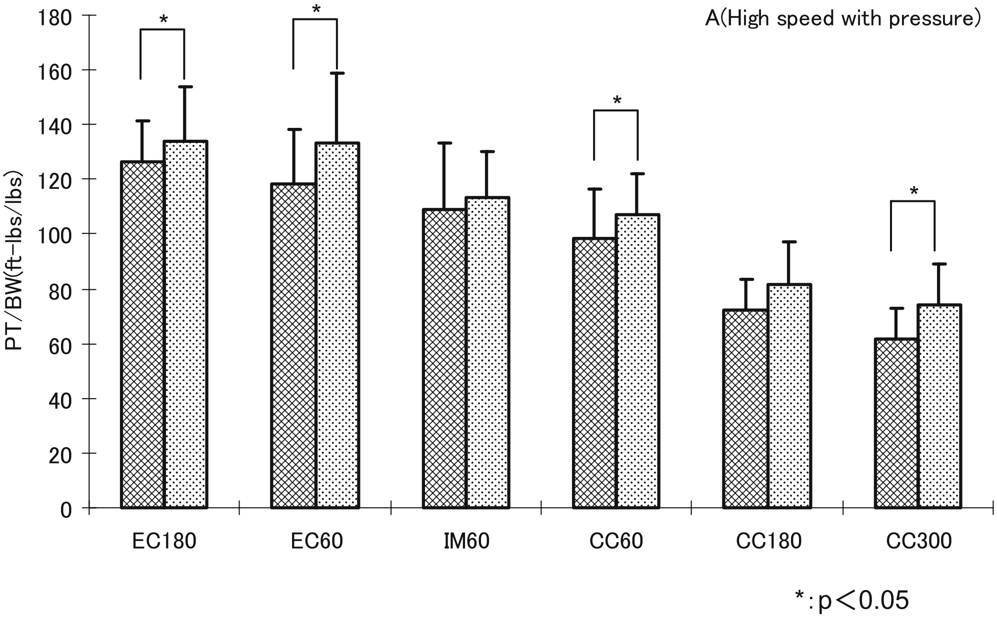

Fig. 1. Group A (high speed with pressure). Peak torque per body weight (PT/BW) of the knee extensor (quadriceps) before and after the resistance test. There was a significant increase with angular velocities of 60°/s and 300°/s for concentric contraction (*CC*) and 60°/s and 180°/s for eccentric contraction (*EC*) ($P < 0.05$). *IM*, isometric contraction

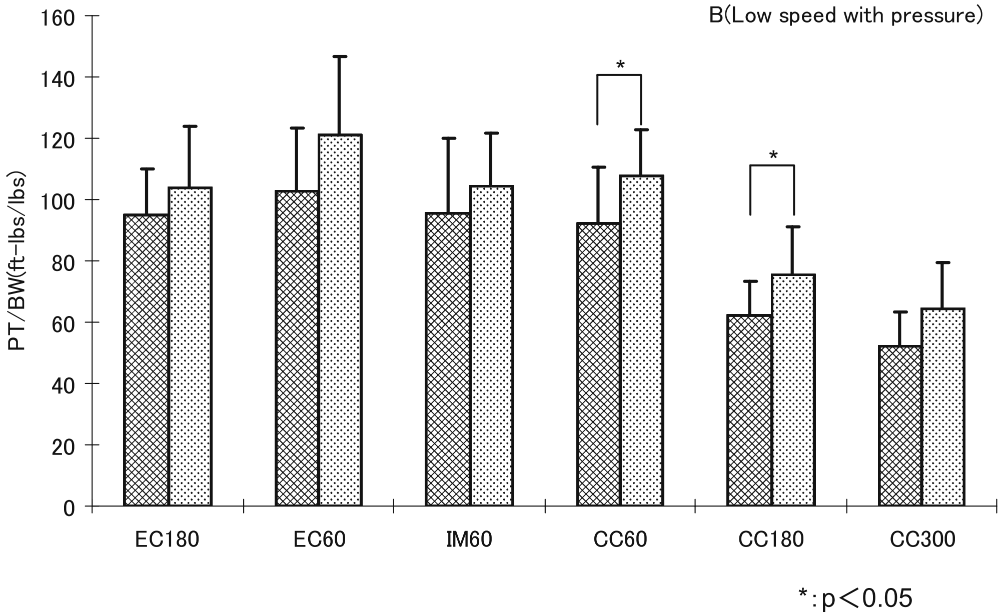

Fig. 2. Group B (low speed with pressure). PT/BW of the knee extensor before and after the resistance test. There was a significant increase with angular velocities of 60°/s and 180°/s for CC ($P < 0.05$)

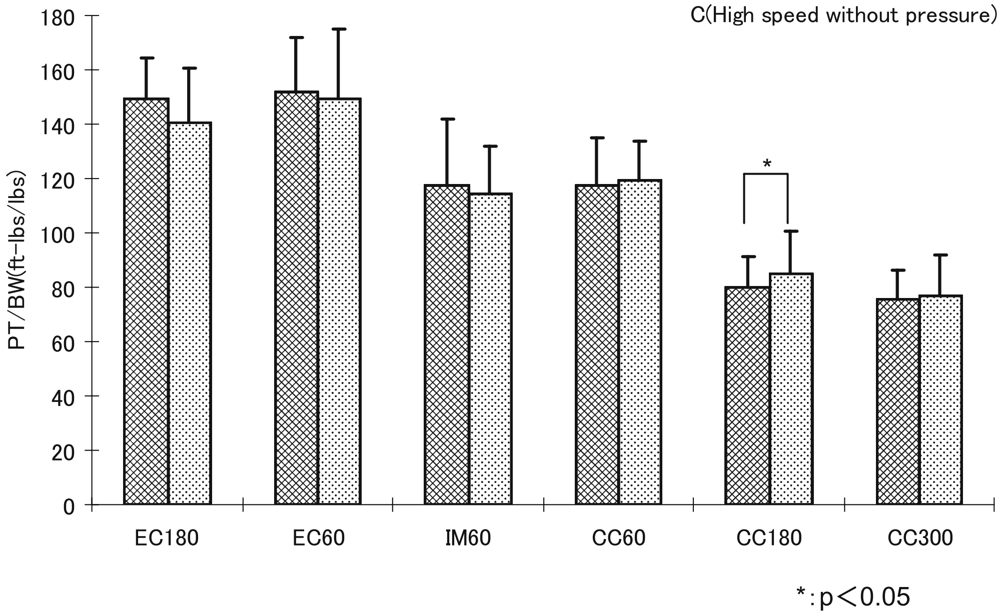

Fig. 3. Group C (high speed without pressure). PT/BW of the knee extensor before and after resistance test. There was a significant increase only with an angular velocity of 180°/s for CC ($P < 0.05$)

Determination of femoral muscle volume by MRI

Before and after resistance training

Figure 8 shows the results of femoral muscle volume determination for groups A and B. The data are expressed as the ratio of the cross-sectional area of the muscle relative to the femoral bone at a level 16 cm proximal from the upper end of the patella. In group A, which had undergone resistance training under high velocity and restricted blood flow, the volumes were 98.5 ± 20.3 and 104.0 ± 15.7 before and after training, respectively. These values showed no significant difference. The volumes for group B, which had undergone training under low speed and restricted blood flow, were 101.1 ± 27.1 and 104.5 ± 28.3 before and after training, respectively. No significant difference was noted between these figures.

Percentage increases in the groups with blood flow restriction

Figure 9 shows the percentage increases in the femoral muscle volume of the groups with blood flow restriction. The percentage increases of groups A and B, which had undergone resistance training under blood flow restric-

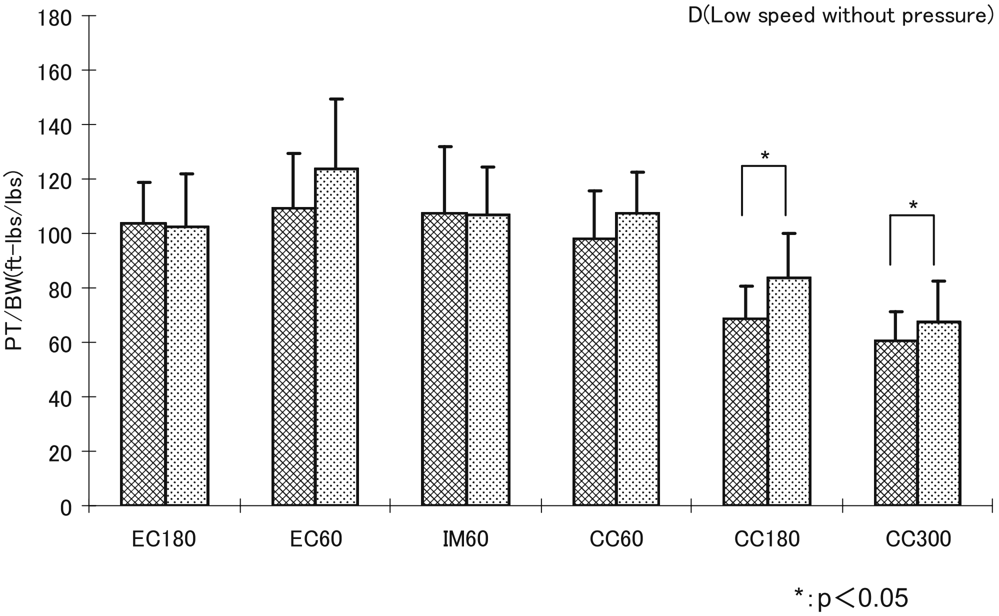

Fig. 4. Group D (low speed without pressure). PT/BW of the knee extensor before and after the resistance test. Group D showed a significant increase with angular velocities of 180°/s and 1300°/s for CC ($P < 0.05$)

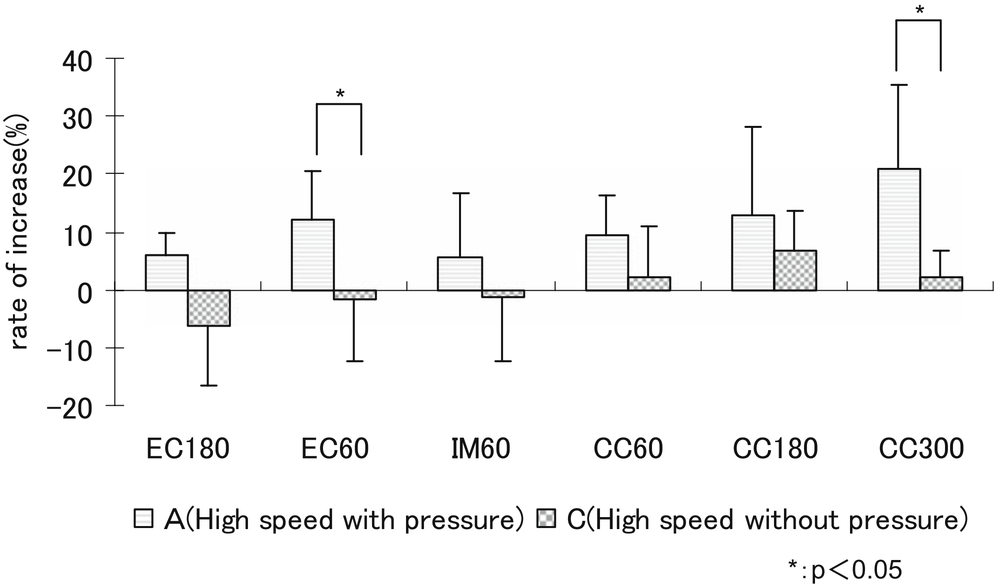

Fig. 5. Rate of increasing quadriceps muscular strength (A vs. C). Comparison of group A (high speed with pressure) versus group C (high speed without pressure) showed significant increases with angular velocities of 300°/s for CC and 60°/s for EC ($P < 0.05$)

tion, were 6.9% ± 12.6% and 3.4% ± 10.1%, respectively. There was no significant difference between them.

Discussion

Knee extensor muscular strength

It is known that resistance training, when conducted at high intensity, causes muscular hypertrophy, improving muscular strength.[3] In the current study, isokinetic resistance training under blood flow restriction with pressure was conducted, and the effects were compared at high and low velocities. In group C, in whom resistance training was conducted at high velocity but without blood flow restriction, the training effect was minimal. However, in group A, where resistance training was conducted at high velocity with blood flow restriction, significant increases were exhibited at many angular velocities (CC and EC) despite the short period (4 weeks) permitted for training. This coincided with a report by Takarada and Ishii,[5] who conducted isokinetic resistance training at low intensity under blood flow restriction with pressure.

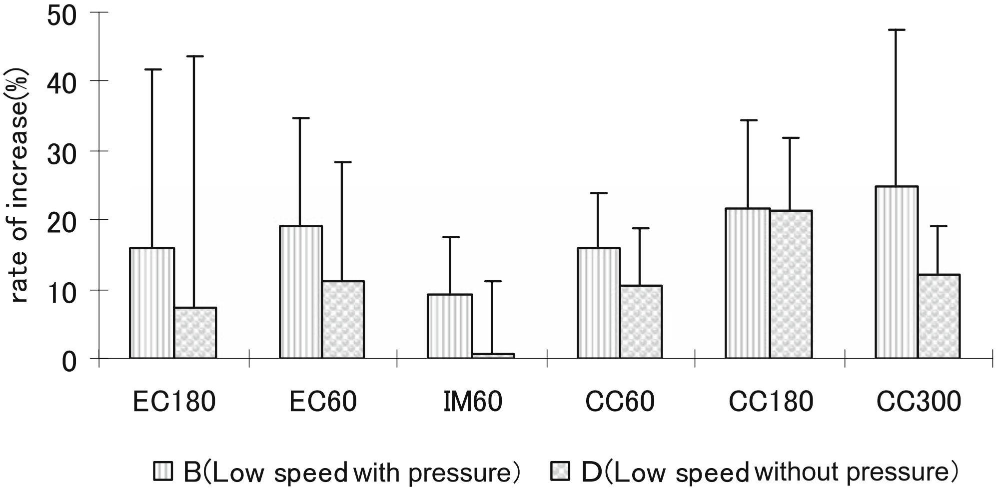

Fig. 6. Rate of increasing quadriceps muscular strength (B vs. D). In a comparison of groups B (low speed with pressure) and D (low speed without pressure), both having undergone resistance training at a low velocity, no significant differences were noted at any angular velocity

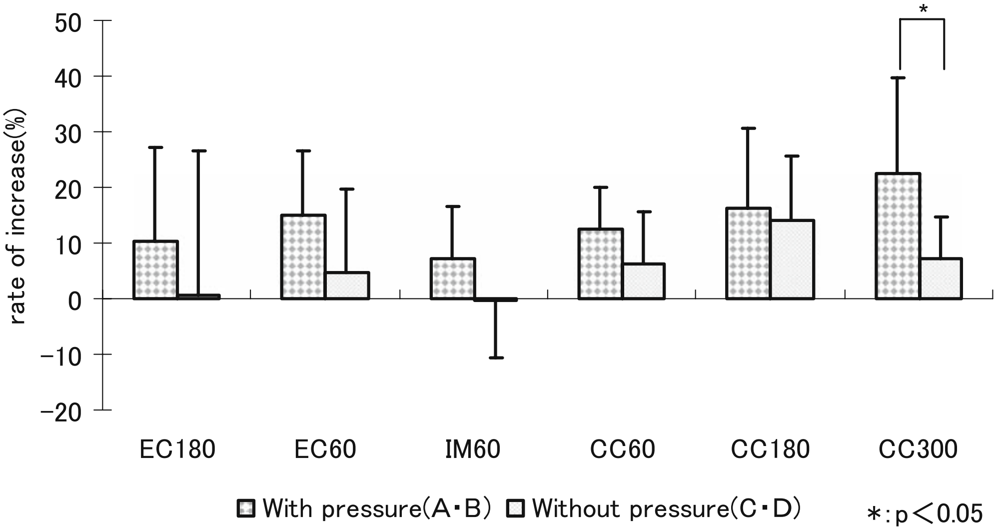

Fig. 7. Rate of increasing quadriceps muscular strength (with pressure vs. without pressure). When the groups with restricted blood flow were compared to those without, it seemed that the large increment was observed at almost angular velocities in the groups where the blood flow was restricted, but a significant difference was observed only at an angular velocity of 300°/s ($P < 0.05$)

When groups A and C were compared for their percentage increases in muscular strength, the former, in which resistance training was conducted under restricted blood flow with pressure, showed a significantly greater increase at angular velocity of 300°/s for CC and 60°/s for EC.

In group B, resistance training was conducted under restricted blood flow with pressure and at low velocity. In group D, resistance training was conducted at the same low velocity without blood flow restriction. These two groups showed a significant increase in muscular strength only for CC. When the percentage increase of the muscular strength in these two groups was compared, group B, which underwent training with blood flow restriction, seemed to have a greater percentage increase at almost all angular velocities; but the difference was not significant.

In a comparison of percentage increases in resistance training at high velocity (group A) and low velocity (group B), both under restricted blood flow with pressure, no significant difference was noted at any of the angular velocities. The average amount of training sat one time for group A was 2839.7 ± 228.2 J, that for group B was 3895.0 ± 1391.8 J, that for group C was 3310.5 ± 596.1 J, and that for group D was 4318.5 ± 945.8 J. In group A, the intensity of resistance training was minimal.

Groups A and B had the same training under blood flow restriction, but the velocity was 300°/s in group A and 90°/s in group B. The intensity of training for group A was 54.6% ± 5.9% of the maximum voluntary contraction (MVC), and that for group B was 80.% ± 9.7 of the MVC. Therefore, there was no significant difference between the rate of increasing quadriceps muscular strength of groups A and B due to different velocity (intensity of training).

Concerning muscle hypertrophy, there was no significant difference in the muscle volume of groups A and

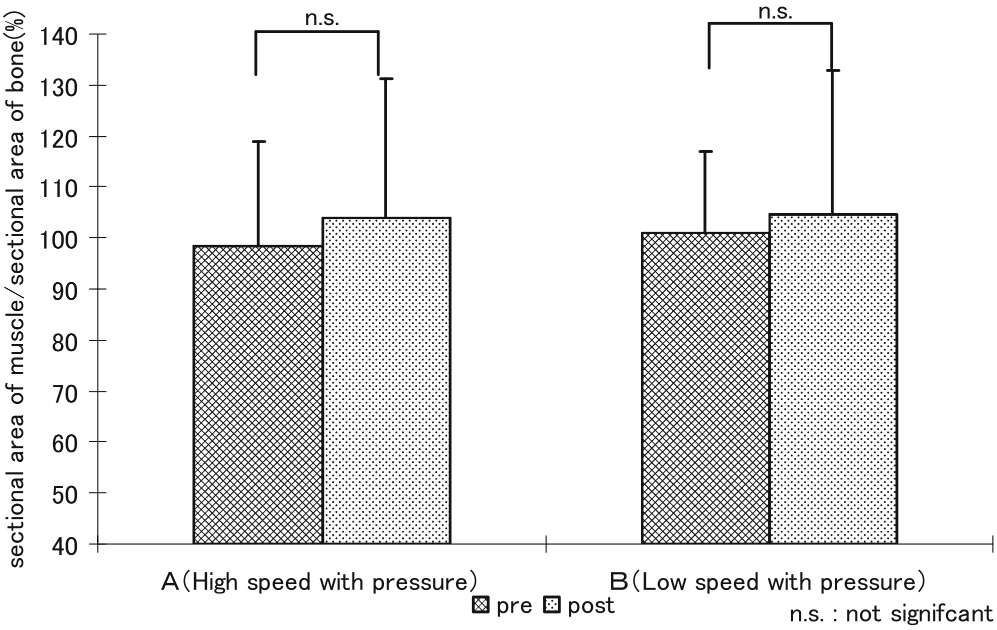

Fig. 8. Muscular volume by magnetic resonance imaging (MRI)

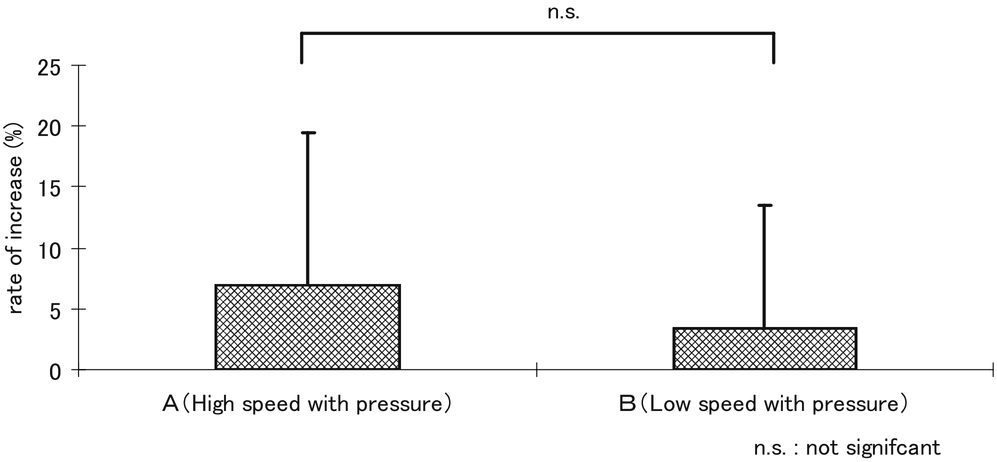

Fig. 9. Rate of increasing quadriceps muscular volume, by MRI. The percentage increases of groups A and B, who had undergone resistance training under blood flow restriction, were 6.9% ± 12.6% and 3.4% ± 10.1%, respectively. There was no significant difference between them

B. It is also known that muscular hypertrophy develops after a certain interval following an increase in muscular strength. The 4 weeks set as the duration of this study was not long enough to result in the development of significant muscular hypertrophy.

According to Takarada and Ishii,[5] resistance training at low intensity conducted under restricted blood flow with pressure, in comparison with that without restriction, resulted in twofold higher blood lactate level; but resistance training at high intensity produced no significant difference in the level of this metabolite regardless of blood flow restriction. It has also been reported that a reduction in the amount of blood supplied to active muscles due to local blood flow restriction raises the activity level of the muscles that are undergoing training at low intensity.[5] In other words, these findings suggest that blood flow restriction in an appropriate manner during low-intensity resistance training may augment muscular strength comparable to a level that is brought about by high-intensity training.

For a mechanism to explain the effect of resistance training under blood flow restriction with pressure, the participation of the endocrine system, such as secretion of growth hormone, is considered. According to a report by Takarada et al.,[6] the concentration of growth hormone increases about 290 times that of normal during resistance training of low intensity (20% of one repetition maximum, or 1RM). In Takarada and colleagues' reports, the plasma concentration of growth hormone was maximum after 15 min, and it returned to a normal level at after 24 h. Hence, it appears that this effect is temporary. Kraemer et al.[15] reported that a rise in the growth hormone level during high-intensity resistance training with short rest periods amounts to

100-fold that before the training. Thus, the fact that low-intensity resistance training (20% of 1RM) raised the growth hormone content to 290 times the normal level suggests that appropriate blood flow restriction by pressure may have an effect even greater than that brought about by high-intensity training.

In the present study, hormone concentrations were not measured, so no detailed conclusion can be drawn on this subject. It is plausible that appropriate blood flow restrictions with pressure in low-intensity training causes muscular hypertrophy or an increase in muscular strength through participation of the endocrine system (e.g., secretion of growth hormone).

In another study, we investigated some muscle fibers by biopsy. Among patients with anterior cruciate ligament reconstruction, we used isokinetic resistance training under a condition of restricted blood flow with pressure for one group and conventional resistance training without pressure for another group. After 16 weeks, we investigated the types of muscle fiber and volumes of type 1 (slow fibers) and type 2 (fast fibers) in the vastus lateral muscle in each of the eight cases. There were no significant differences in size or volume between the type 1 and type 2 fibers. Type 1muscle fiber needs more oxygen and hence more blood flow. Therefore, we had thought that type 2 muscle fibers (fast fibers) would react more than type 1 muscle fibers (slow fibers) under the blood flow-restricted condition, but there were no suggestive differences. Currently, there are no useful reports about the exact mechanism of the effect of blood flow restriction. Further studies are required to clarify the underlying mechanism of such restriction.

Determination of femoral muscle volume

In the muscle volume determination by MRI in the current study, no significant increase was noted after training. Neither was there a significant difference in a comparison of percentage increases among the groups with blood flow restriction with pressure. It has been theorized that muscular hypertrophy may be caused by the exaggerated synthesis of actin and myosin, the proteins of which muscle fibers are composed, with a resultant increase in the myofibrils in muscle fibers. It is known that muscular hypertrophy develops after a certain interval following an increase in muscular strength. In other words, an increase in muscular strength at the initial stage of resistance training is a form of adaptation of the nervous system and is not associated with muscular hypertrophy. It is believed that normally for about 20 days after the start of training muscle strength that occurs is not associated with muscular hypertrophy. Therefore, the 4 weeks set as the duration of this study was not long enough to result in the development of significant muscular hypertrophy.

It is commonly believed that highly intense resistance training is required to develop muscular hypertrophy. It has been reported, however, that it can occur even with low-intensity resistance training by adequately restricting the blood flow. Takarada and Ishii[5] reported that 16 weeks of resistance training under blood flow restriction with pressure resulted in the development of significant muscular hypertrophy in aged women. Fujino et al.[16] compared the results of resistance training under blood flow restriction with pressure and conventional resistance training as a rehabilitation program for patients with injuries to the anterior cruciate ligament: They reported a significant increase in the cross-sectional area of the muscle and the femoral circumference. On the other hand, Ota et al.[17] stated that 8 weeks of resistance training under blood flow restriction with pressure resulted in an increase in muscular strength; but no significant increase was noted in the cross-sectional area of the muscle. These discrepancies in the results reported in these studies may be due to differences in the test subjects, training methods, methods of measuring various parameters, and other factors. The current study did not detect a significant increase in the muscle volume, but the authors hope to investigate the merit of muscle hypertrophy associated with resistance training under restricted blood flow with pressure by reevaluating such factors as the duration and frequency of training.

Conclusions

The present study covered a short period (4 weeks), but it succeeded in indicating an obvious difference in the percentage increase in muscular strength due to training conditions. Resistance training with restricted blood flow, rather than without it, resulted in greater muscular strength. During this resistance training under restricted blood flow with pressure, no subject suffered any notable injuries. These findings indicated that localized restriction of blood flow in low-intensity resistance training under isokinetic conditions produces an effect comparable to that obtained by high-intensity resistance training in well-trained athletes.

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