Circuit training without external load induces hypertrophy in lower-limb muscles when combined with moderate venous occlusion

N. Ishii, H. Madarame, K. Odagiri, M. Naganuma, K. Shinoda

The present study investigated whether circuit training with body weight alone (no external load) can cause muscular hypertrophy when combined with moderate venous occlusion ('Kaatsu Training'). Healthy women (mean age, 32.7 ± 4.0 yr; n=22) were randomly assigned into the occlusive training group (OCC, n=11) and the normal training group (NOR, n=11). Both groups performed the same circuit-training regimen consisting of six, successive exercises for muscles in the upper and lower limbs and the trunk, at a frequency of 3 sessions/wk. Each session lasted for 5-10 min. In OCC group, proximal ends of the upper and lower limbs of both sides were moderately compressed by means of 'KAATS Sportswear', to restrict the venous blood flow during the exercises (preset pressure, 50-80 mmHg and 80-120 mmHg for upper and lower limbs, respectively). Cross-sectional area (CSA) of the thigh muscle was measured with spiral computer tomography. After an 8-wk period of training, the muscle CSA of both right and left limbs showed significant increases by ~3% (P<0.05) in the OCC group, whereas there was no change for the NOR group. To propose a mechanism for these findings, the acute effects of the same exercise regimen combined with occlusion on plasma concentration of growth hormone (GH) were further investigated with male subjects (n=2). The circuit exercise with occlusion elicited a dramatic increase in plasma GH, whereas that without occlusion did not, although statistical analysis could not be made. The results indicate that circuit training with only body weight can cause hypertrophy in lower-limb muscles when combined with moderate venous occlusion, but the exact mechanism is not yet understood.

Key words: exercise intensity, growth hormone, Kaatsu training, muscle cross-sectional area, training with body weight

INTRODUCTION

The effects of resistance exercise training are known to depend on the exercise intensity, the exercise volume, and the length of rest period between sets (for review, see Ishii, 2002). Briefly, resistance exercise with middle to high intensity, e.g., ~80% of one-repetition maximum (1RM), and relatively large volume (number of exercises x number of repetitions x number of sets) causes muscular hypertrophy and concomitant increases in strength, when performed with relatively short rest periods between sets (~1 min). On the other hand, exercise with an intensity of <65% of 1RM generally induces an improvement of muscular endurance with no substantial increases in muscular size and strength (McDonagh and Davies, 1984).

The above principle related to the intensity-dependence of the training effect appears to be pertinent, at least partially, for circuit weight training, where the aim is to gain both muscular strength and endurance simultaneously. Circuit weight training has been developed as a form of resistance training with a series of exercises performed with short or no inter-set rest periods. It has been demonstrated that circuit-training regimens with an intensity of 40-60% of 1RM can cause strength gains (Wilmore et al., 1978; Gettman et al., 1978,1980, 1982). This fact is consistent with the study by Takarada and Ishii (2002) showing that resistance exercise with an intensity of ~50% of 1RM successfully causes gains in muscular size and strength when performed with a short inter-set rest period of 30 s. On the other hand, the effects of circuit training with much lower intensities, including that with only body weight and no added external load, have not been studied well, and this type of exercise training has been thought to be virtually ineffective for gaining muscular size and strength. However, circuit training with only body weight is so accessible to a wide range of people that it is worth studying potential methods that might augment its effect.

Recent studies have shown that resistance exercise with an intensity as low as 20-50 % of 1RM can effectively cause increases in muscular size and
strength when combined with moderate restriction of blood flow within the working muscles (Takarada et al., 2000b, 2002). This type of resistance exercise with vascular (venous) occlusion, termed ‘Kaatsu training’, has been shown to evoke an increase in muscle-fiber recruitment (Moritani et al., 1992, Takarada et al., 2000b) and enhanced endocrine responses (Takarada et al., 2000a), both of which are related to the trophic effect on muscle.

The present study investigated whether circuit training with only body weight combined with weak-to-moderate vascular occlusion effectively induces muscular hypertrophy in lower limb muscles.

**METHODS**

**Subjects**

Twenty-two healthy women (age, 28-44 yr; 32.7 ± 4.0 yr) without prior experience of regular resistance training volunteered. They were randomly assigned into the occlusive training group (OCC, n=11) and the normal training group (NOR, n=11). Their age, height and body mass were (mean ± S.D.): 33.1 ± 4.4 yr (range, 28-44 yr), 159.2 ± 3.9 cm and 54.5 ± 5.8 kg, respectively, in OCC; 32.4 ± 3.5 yr (range, 28-40 yr), 159.2 ± 4.3 cm and 53.2 ± 4.5 kg, respectively, in NOR. No particular request was given in addition to regular training during the experimental period. Blood sampling was impossible because they were participants in health-related service programs for citizens, therefore, a pilot study on plasma growth hormone was conducted separately with two male volunteers (see below). All subjects had been fully informed about the purpose of the study and the possible risks involved, and gave their written informed consent. All procedures followed the guidelines by the Ethics Committee for Human Experiments, University of Tokyo.

**Exercise training**

Both groups performed the same circuit-training regimen consisting of six successive exercises for major muscle groups in the upper and lower limbs and the trunk (Table 1). The exercises used were (in the actual order): knee up, bent-knee push up (push up with the knees on the floor), leg raise, seated knee flexion (‘knee-to-chest’), squat and forward lunge. Basically, all exercises were performed in a step-by-step fashion essentially without a rest period, though a brief interval of ~ 10 s was typically required to prepare for the next exercise. The frequency and the period of exercise were 3 sessions /wk and 8 wk, respectively. The repetitions in each exercise and the round number (set number in Table 1 also means the round number) were occasionally increased as the training proceeded. In OCC group, the subjects wore ‘KAATS Sportswear’ (PHENIX Co. Ltd., Tokyo, Japan) during the entire session of exercise lasting typically for 5 min (1 round) to 10 min (2 rounds). The proximal ends of upper and lower limbs of both sides were moderately compressed to restrict the venous blood flow by means of elastic belts attached to the sleeves and the pants. The occlusive pressure was previously calibrated with respect to the stretch distance of the elastic belt and the circumferences of the upper- and lower-limbs, and preset at 50-80 mmHg for the upper limbs and 80-120 mmHg for the lower limbs in each subject individually, which are defined as weak to standard levels according to the recommendations of the manufacturer. These ranges in pressure were due to the limitation in adjusting the elastic force for each subject, and the preset pressure was kept unchanged in each subject throughout the period of training.

**Measurement of muscle cross-sectional area**

Cross-sectional area (CSA) of both right (OCC-R, NOR-R) and left (OCC-L, NOR-L) thigh muscles was measured with spiral computer tomography (spiral CT; Pro Speed FI, GE Yokogawa Medical Systems, Tokyo, Japan) before and immediately after the 8-wk training period. Eleven serial sections were acquired at a 10-mm section thickness and a 10-mm intersection gap. Cross sections at 20cm distal from the proximal end of the femur were chosen for analysis and the area occupied by the thigh muscles (quadriceps, hamstrings and adductor muscles) was

---

**Table 1. Regimen for circuit training**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>1 reps set</th>
<th>2−4 reps sets</th>
<th>5−6 reps set</th>
<th>7−8 reps sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee up</td>
<td>30 1</td>
<td>30 2</td>
<td>40 2</td>
<td>50 2</td>
</tr>
<tr>
<td>Bent knee push up</td>
<td>10 1</td>
<td>10 2</td>
<td>15 2</td>
<td>20 2</td>
</tr>
<tr>
<td>Leg raise</td>
<td>10 1</td>
<td>10 2</td>
<td>15 2</td>
<td>20 2</td>
</tr>
<tr>
<td>Seated knee flex</td>
<td>10 1</td>
<td>10 2</td>
<td>15 2</td>
<td>20 2</td>
</tr>
<tr>
<td>Squat</td>
<td>20 1</td>
<td>20 2</td>
<td>25 2</td>
<td>30 2</td>
</tr>
<tr>
<td>Forward lunge</td>
<td>20 1</td>
<td>20 2</td>
<td>20 2</td>
<td>20 2</td>
</tr>
</tbody>
</table>
measured with custom made software. CSA of the upper-limb muscles were not measured, because reproducible images could not be acquired due mainly to the limitation of the scanner settings.

Blood sampling and analyses

To see if the vascular occlusion causes an effect on the circulatory hormone levels, plasma concentration of growth hormone (GH) was separately measured with two male subjects. Their age, height and body weight were 26-39 yr, 164-175 cm and 56-63 kg, respectively. The exercise regimen was the same as that for the initial week in the long-term experiments with women (Table 1). Also, vascular occlusion was given by means of ‘KAATS Sportswear’ at the same occlusive pressures as previously described. Exercise sessions with and without vascular occlusion were separated by 1 wk, and each exercise session was taken at the same time (10-11 a.m.) of the day. The subjects were asked to refrain from eating for at least 6 hours before the exercise session. Venous blood samples (10 ml for each point of measurements) were taken from the antecubical vein in a seated position before and after the exercise. Plasma concentration of total immunoreactive GH was measured with standard radioimmunoassay at the Institute for Public Health, Tokyo, Japan.

Statistical analysis

Data are expressed as means ± S.D. A two-way analysis of variance (ANOVA) with repeated measures (two groups x pre- and post-training) was made for each of the right and left limb muscles. Student’s paired t-test was used to compare differences between pre- and post-training values within the same groups. The level of statistical significance was set at P<0.05.

RESULTS

Changes in muscle cross-sectional area (CSA)

After an 8-wk period of training, the mean muscle CSA of both right and left limbs showed increases by ~3% in the OCC group, whereas no apparent change was seen for the NOR group (Fig.1). For the right-limb muscles (OCC-R and NOR-R), a two-way ANOVA showed a significant interaction (P =0.019) between groups and changes in CSA, indicating that training with occlusion and normal training caused different effects on the muscle CSA. However, no significant interaction was seen for the left-limb muscles (OCC-L and NOR-L, P =0.099). On the other hand, in both right and left limbs, the post-training values of muscle CSA showed significant increases from the pre-training values in the OCC group (OCC-R, P =0.045; OCC-L, P =0.026), but not in the NOR group.

Plasma concentration of GH

Changes in plasma concentration of GH are shown in Fig.2. The measurement was made as a pilot study to see whether changes in circulating hormone levels occur after the exercise with vascular occlusion, as has been shown by Takarada et al. (2000a). The sample number was so small (n=2) that data could not be subjected to statistical analysis. In spite of such a limitation, however, the plasma concentration of GH showed considerably larger increases after the exercise with vascular occlusion than after the normal exercise, implying the strong potential of a low-intensity circuit exercise with vascular occlusion.

---

**Fig.1** Cross-sectional area (CSA) of thigh muscle measured before and after the training. Values are means and SD. *, significant changes from pre-training values (P <0.05). #, significant difference between groups (P <0.05).

**Fig.2** Changes in plasma concentration of growth hormone (GH) after exercise with (■) and without occlusion (□). Means for 2 subjects (± SD) are shown.
to enhance the GH responses.

**DISCUSSION**

The present study showed that circuit training with only body weight caused hypertrophy in thigh muscles, when combined with moderate venous occlusion. Since the same exercise regimen without vascular occlusion did not cause significant changes in muscle CSA, the vascular occlusion can be regarded as the primary factor responsible for the muscular hypertrophy. However, the extent of hypertrophy was small (by −3%) when compared to previous studies on low-intensity resistance exercises with vascular occlusion, e.g., by −20% for elbow flexor muscles (Takarada et al., 2000b) and by −12% for knee extensor muscles (Takarada et al., 2002).

There appears to be at least two reasons for the relatively small effect of the present exercise training on inducing muscular hypertrophy. First, the occlusion pressure was much lower for both upper (50-80 mmHg) and lower limb muscles (80-120 mmHg) than in the previous studies, e.g., ~110 mmHg for upper arms (Takarada et al., 2000b) and ~200 mmHg for legs (Takarada et al., 2000a, 2002a). The present occlusive pressure may have had a sufficient effect at the initial stage of exercise training, because it caused marked increases in blood GH (Fig.2) and lactate concentrations (data not shown). However, some adaptation against the occlusive stimuli may have taken place in blood vessels and/or surrounding tissues which might diminish the training effect as the exercise training proceeded. Secondly, the exercise regimen itself may contain some problems. The period of exercise training in the present study (8 wk) was much shorter than in previous studies (12-16 wk) and may therefore be insufficient to complete the time course needed to ensure adequate muscle hypertrophy. In addition, the present exercise regimen contained only two major exercises for lower limb muscles (squat and forward lunge). Although these exercises are relatively strenuous, in that the body weight directly serves as load, one or two sets for each exercise in a session may be an inadequate exercise volume.

It has been shown that one of the plausible mechanisms underlying the effects of resistance training with vascular occlusion is an enhanced endocrine response (Ishii, 2002). Takarada et al. (2000a) have demonstrated that five sets of knee extension exercises with vascular occlusion at an intensity as low as −20% of 1RM can cause dramatic increases in the plasma concentrations of GH and noradrenaline. Although precise roles played by GH in exercise-induced muscular hypertrophy have not been fully established, it has been shown that acute changes in plasma concentration of GH after exercise are positively correlated with the extent of muscular hypertrophy after the period of exercise training (McCall et al., 1999).

With regard to the GH response, the present circuit exercises with vascular occlusion showed a tendency to elicit a marked increase in plasma GH (Fig.2), the amplitude of which was comparable with those reported by previous studies (McCall et al., 1999, Takarada et al., 2000a). Although the present study measured plasma concentrations of GH with men, the GH responses to resistance exercise regimens are thought to be similar between men and women (Kraemer et al., 1991). Therefore, the present regimen might cause strong endocrine responses in both men and women, likely by activating successively the muscles of both upper and lower limbs that are subjected to vascular occlusion. On the other hand, our recent study showed that increases in GH and/or other muscle-trophic factors after resistance exercise with vascular occlusion did not cause hypertrophy in completely untrained muscles (Madarame and Ishii, in preparation). This suggests that some combination between circulating factors such as hormones, and the exercise stimulus itself, are essential for muscular hypertrophy. Therefore, increasing the total exercise volume for the lower limb muscles may have to be considered for gaining muscular size more effectively.

In conclusion, circuit training with only body weight is potentially effective in eliciting acute hormonal responses and inducing muscular hypertrophy, when combined with moderate vascular occlusion. Although such types of circuit training would be highly useful for people without physical strength, the development of more appropriate exercise regimens for those who are more fit would be essential.

**References**


McDonagh MJ, Davies CT (1984) Adaptive response of mammalian...


Authors’ affiliations
N. Ishii, H. Madarame, Department of Life Sciences, Graduate School of Arts and Sciences, University of Tokyo, Komaba, Tokyo 153-8902, Japan.
K. Odagiri, Odagiri Hospital, Nakahara-ku, Kawasaki-shi, Kanagawa 211-0063, Japan.