Original Article

Effects of low-intensity resistance exercise with vascular occlusion on physical function in healthy elderly people

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Summary **Some successful fall prevention programs include resistance or balance training, but less is known about the effects of low-intensity resistance exercise with moderate vascular occlusion (LIO) on physical function in healthy elderly people. In LIO, appropriate pressure is applied to the proximal parts of the upper and lower extremities with a specially designed belt. The reduction of muscle blood flow is considered likely to induce the secretion of growth hormone. The aim of this study was to compare the effects of two training programs, LIO versus dynamic balance exercise (DBE) in elderly people in a community. Fifty-one healthy subjects aged 65 and older were randomly assigned to the LIO program (*n* = 24) or the DBE program (*n* = 27). Performance, balance, muscle strength were measured in both groups before and after the 8-week programs. In addition, blood was sampled from LIO participants (*n* = 11) and analyzed for growth hormone and lactate. Overall improvements, but no group differences, were found in performance and balance after the programs. Muscle strength in the lower extremities was significantly increased in the LIO group, but not in the DBE group. Growth hormone was significantly increased immediately after LIO. The 8-week LIO program improved physical function, especially muscle strength, which may be associated with the exercise-induced secretion of growth hormone. Further studies are needed to determine the contents and duration of an LIO program for elderly people.**

Keywords: Vascular occlusion, Growth hormone, Elderly

1. Introduction

Muscle strength is one of the predictive factors for functional decline in the aged population. Lower limb muscle strength in the elderly is associated with walking ability (*1*) and activities of daily living (ADL) (*2*). Performing exercises such as walking, jogging, or recreational physical activities on a regular basis has been reported to improve muscle strength, flexibility, endurance, and balance in older adults (*3*). In addition, an intervention study on falls prevention demonstrated the beneficial effects of training for the improvement of muscle strength and balance (*4*). Exercise programs including balance training are also often recommended for reducing the risk of falling. Dynamic Balance Exercise (DBE), which consists of slow, rotational and multisegmental movements with sequential weight shifting, has been shown to improve balance responses (*5*). Balance retraining program including DBE was shown to be practical and useful in fall risk reduction (*6*).

The effects of resistance training have been evaluated using a number of indicators, such as muscle strength of the muscle group to be trained, lean body mass, bone density, lower back pain, muscle function, and performance, including walking velocity and stair ascension and descension (*7*). A meta-analysis of 62 randomized comparative studies has demonstrated that lower limb muscle strength and walking velocity are

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useful indicators for evaluation (*8*).

Exercise at an intensity equal to or higher than 65% of 1 repetition maximum (1-RM) has been shown to improve muscle strength (*9*). Muscle strength can also be improved by a 20-25% low-intensity resistance exercise combined with moderate vascular occlusion (LIO) in active muscle groups (*10*). The level of muscle strength required for LIO is almost equivalent to that of daily living activities. In this method, low intensity training is performed while applying appropriate pressure to the proximal parts of the upper and lower limbs with a pair of special elastic belts for a given length of time. In the study by Takarada *et al*. (*10*), plasma levels of growth hormone, norepinephrine, and lactate were remarkably increased after the exercise with occlusion. Furthermore, LIO for a short-time and low-intensity exercise had a significant effect equal to or greater than high-intensity resistance training on an increase in muscular size and strength (*11*). Among a number of intervention studies designed to slow functional decline, none has been conducted to closely examine performance, muscle strength, and balance in healthy elderly people by using LIO.

The primary effect of DBE is to improve balance, and muscle strength and performance are also expected to increase through the exercise. However, no study has ever compared DBE and LIO directly. In addition, although a significant increase of growth hormone was observed after LIO in young subjects, there has been no data available for the elderly. Therefore, the purpose of the present study was twofold: 1) to determine whether LIO is equally or more effective than DBE regarding performance and balance, and muscle strength and 2) to measure changes of growth hormone and lactate before and after a single bout with LIO, in community-dwelling healthy elderly people.

2. Materials and Methods

2.1. *Study design and subjects*

The current study was designed to compare the effects of two different training programs. In April 2004, we compiled a list of all residents aged 65 years and older living in a village in Nagano Prefecture. Among them, 350 people were excluded due to long-term nursing care, hospitalization, or death. Healthcare volunteers distributed a description of the physical training programs to the remaining 1,864 people. In June 2004, eighty-seven of them underwent medical check-ups. A public health nurse explained the contents and schedule of the LIO and DBE programs.

The exclusion criteria were as follows: 1) unable to participate in training sessions for 8 weeks; 2) joint or muscular problems as a result of daily exercise; 3) uncontrolled hypertension: systolic pressure of over 160 mmHg and/or diastolic pressure of over 100 mmHg (those who had controlled blood pressure under antihypertensive therapy were considered eligible); 4) chronic inflammatory conditions; 5) history of myocardial infarction within the last 6 months; and 6) severe paralysis, joint degeneration, or arthralgia in their extremities. In addition, we excluded subjects who were suspected of being at high risk of developing venous thrombosis or other cardiovascular diseases. Among the 87 people who underwent the check-ups, 19 were excluded due to medical problems. Of the 68 who were screened, 51 agreed to participate in the study and signed an informed consent. They were randomly assigned to an 8-week program of either LIO (n = 24) or DBE (n = 27) (Figure 1). The Medical Ethical Committee of Shinshu University School of Medicine approved the protocol of the study.

2.2. *Training protocol*

2.2.1. *LIO program*

Low intensity training was performed while applying appropriate pressure to the proximal parts of the thighs with a pair of special elastic belts (width 45 mm, length 1,250 mm). A physical therapist and a public health nurse served as instructors on the training program twice a week for 8 weeks. Twenty-four subjects were divided into 5 groups and participated in 45-min training sessions (Figure 2). Those with systolic pressure over 140 mmHg before the training were instructed to take a rest until the pressure dropped below that level. In the event that their systolic pressure did not drop, they did exercises without a belt. The belt contained a small pneumatic bag (width 33 mm, length 140 mm) along its inner surface that was connected to an electronic pressure gauge (model M.P.S.-700 developed by Y. Sato and manufactured by VINE Medical Instruments, Tokyo, Japan). A varying level of occlusion pressure was applied through pneumatic inflation. The level of pressure applied during the training was determined according to the age and blood pressure of the subjects. The initial pressure on the thighs was set at 70 mmHg, a pressure level where peripheral blood flow is not impaired. The maximum pressure was set at up to 1.2 times the systolic blood pressure level of individual subjects or at a subjectively tolerable level. Applied pressure from the belt was to be released immediately if there was any complaint of discomfort during the training. Table 1 represents a flow of the 8-week LIO training.

The training program consisted of 6 different movements: lowering the body until the knees are flexed at a 60 degree angle (half squats); stepping forward with one leg and lowering the body to 90 degrees with both knees (forward lunges); raising heels up and down in a standing posture (calf raises); lifting one knee and then the other up to waist level, alternating legs (knee lifts); lying on the floor with knees bent and hands

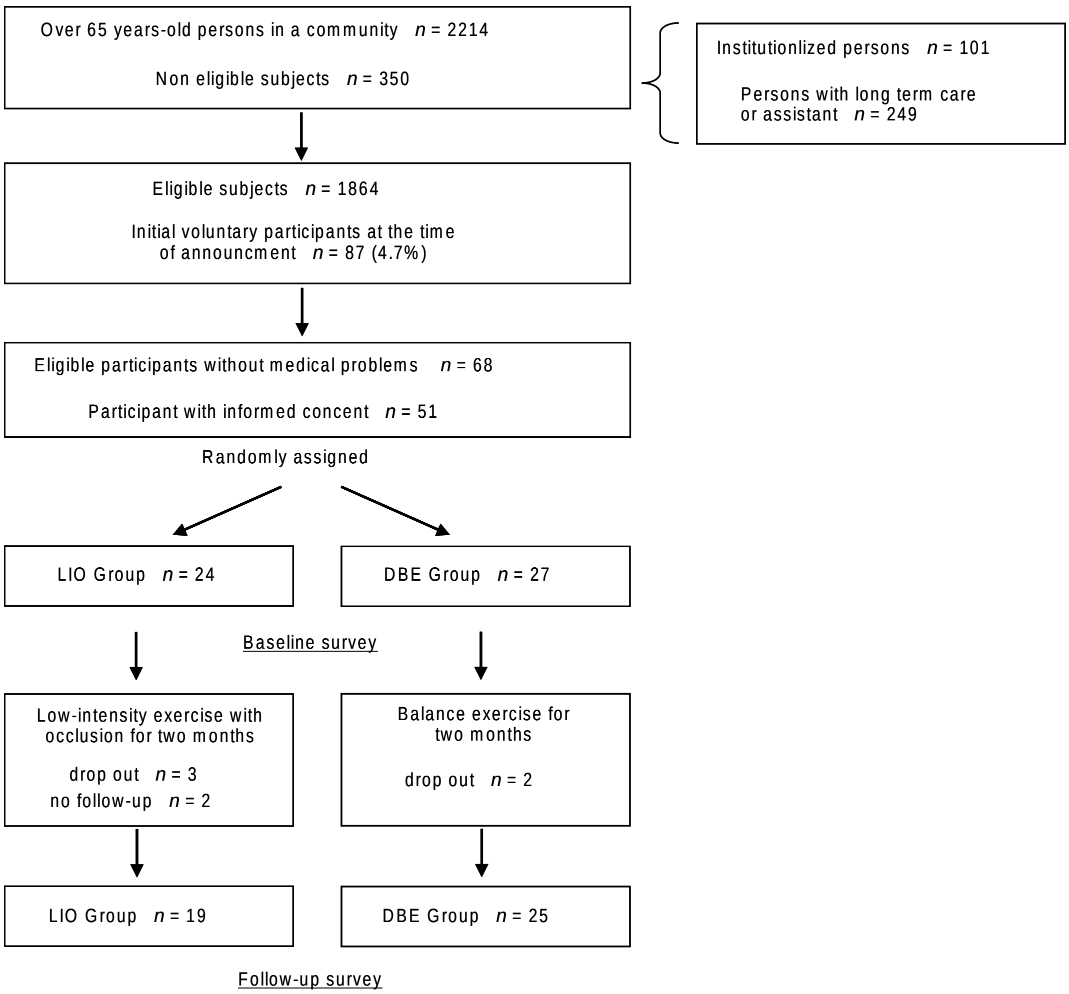

Figure 1. Sampling process.

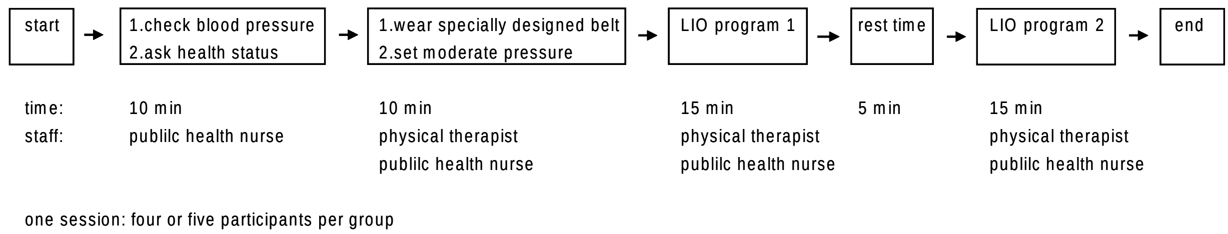

Figure 2. One LIO program session.

behind head, then raising the head and shoulders until the shoulder blades are clear off the floor (crunches); and flexing and extending the knees while sitting on the edge of a chair (knee flexion and extension while seated).

2.2.2. *DBE program*

The aim of the DBE program was to enhance skill in posture position and dynamic stability. The same physical therapist and public health nurse who took part in the LIO also served as instructors on the DBE program once a week for 8 weeks. Twenty-seven subjects were divided into 2 groups, each of which participated in 90-min training sessions. The following was the content of the DBE instruction: symmetrical and asymmetrical movements; forward and lateral reach; forward and backward steps; standing and walking on a reduced base of support; increasing the complexity of ambulatory tasks; and functional ankle strengthening. Movements were performed on two balance mats (80 mm high × 600 mm wide × 600 mm deep, Toyoda Gosei Co., Ltd., Nagoya, Japan).

2.3. *Evaluation 1: Physical function tests*

In July 2004, we asked subjects concerning their basic

Table 1. Eight-week course of low-intensity exercise with occlusion

Period	Max Belt Pressure	Schedule
Week 1	70-80 mmHg	Orientation,5 sets of 10 repetitions of 6 different movements.
Week 2	90-100 mmHg	3 sets of 10 repetitions of 6 different movements. Rest for 5 min. 2 sets of 10 repetitions of 6 different movements.
Week 3	110-120 mmHg	Same as week 2
Week 4	130-140 mmHg	Same as week 2
Week 5	140-150 mmHg	4 sets of 10 repetitions of 6 different movements.
Week 6	140-150 mmHg	3 sets of 15 repetitions of 6 different movements, adding 20-sec breaks between sets.
Week 7	140-150 mmHg	Same as week 6
Week 8	140-150 mmHg	Same as week 6

characteristics such as sex, age, family structure, current health status, and history of falls. The 8-week intervention was conducted from late July to early September that year. Various physical functions as stated below were evaluated before and after the intervention period.

2.3.1. *Performance*

The following 4 items were measured. 1) Reaction time: subjects jumped from a standing posture as quickly as possible in response to optical stimulation. Time from stimulation to the onset of performance was measured. The shorter the reaction time, the greater the level of quickness. 2) Timed up and go test (hereinafter referred to as "TUGT"): after standing up at a given signal from a seated position on a chair, the subjects walked up to and around a target object 3 meters away and then returned to sit down on the chair (*12*). The time taken to complete the process was recorded. 3) Ten-meter walking time: time taken to walk as fast as possible on a 10-meter straight line was measured. 4) Maximum step distance: the length of a step taken as far forward as possible from a standing position was determined.

2.3.2. *Balance*

Functional reach and the duration of time spent standing on one leg were measured. In functional reach, subjects first stood comfortably upright and then reached forward as far as possible without stepping or losing their balance (*13*). As for standing on one leg, the duration was measured with eyes open and looking at an object 1.5 meters ahead.

2.3.3. *Muscle strength*

Grip strength was measured by a digital handgrip dynamometer (Takei Scientific Instruments Co., Ltd., Tokyo, Japan). Isometric knee extension muscle strength was measured in a sitting position at a knee angle of 90 degrees using a dynamometer, GT-30 (OG Giken Co., Ltd., Tokyo, Japan).

2.4. *Evaluation 2: Blood tests*

In order to evaluate the biochemical parameters, plasma levels of growth hormone and lactate were measured in 11 subjects (3 males and 8 females) who participated in the 8-week LIO program and consented to blood sampling. On the 6th week, LIO with belt pressure of 140 to 150 mmHg was performed for 15 min. Blood was then taken from the 11 subjects, who were instructed to eat more than 2 h before the start of the session. The timing of blood collection was before, after, and 15 min after the session (*10*).

2.5. *Statistical analysis*

All analyses were performed with StatView package (ver. 5.0 SAS Institute Inc., Cary, North Carolina, USA) and the significance level was fixed at 5%. The results of physical function tests were analyzed to evaluate differences due to group (LIO versus DBE) and time (baseline versus follow-up) by using repeated measures ANOVA. Regarding characteristics of subjects, age difference between LIO and DBE was compared by *t*-test, and chi-square test was used for the rest of parameters. One-way repeated measures ANOVA was used to compare the variance of growth hormone and lactate before, after, and 15 min after the LIO.

3. Results

Participants in the two groups were similar at the baseline for demographics, presence of chronic diseases, self-rated health, self-reports of falls and physical activity (Table 2). The mean age of those who completed the final evaluation was 70.7 ± 4.3 of LIO and 70.6 ± 5.0 of DBE, ranging from 65 to 79 years. Mean participation frequency were 14.2 ± 1.5 times out of a total of 16 times (88.8%) in the LIO and 6.5 ± 1.4 times out of a total of 8 times (81.3%) in the DBE group. No subjects reported serious adverse effects as a result of the programs.

In the LIO group, 19 out of the 24 subjects completed the final evaluation. Three subjects dropped out, of whom one participated 9 times and the others participated only once. Two people failed to undergo follow-up evaluation after the completion of the program. The reasons for not attending the follow-up were poor physical condition and family problems, respectively. In the DBE group, 25 out of the 27 subjects completed the final evaluation. Two people dropped out after attending the program only once (Figure 1).

3.1. *Evaluation 1: Physical function tests*

Table 3 shows the result of physical function tests before and after the two programs. Both the LIO and DBE programs brought improvements in reaction time, maximum step distance, 10-meter walking time, functional reach test, and standing on one leg (both leg). In repeated measures ANOVA for measuring interactive effects by groups and types of intervention, TUGT and knee extension in the LIO group were items that showed significant improvement (TUGT, $p < 0.001$; left knee, $p < 0.001$; right knee, $p = 0.007$).

3.2 *Evaluation 2: Blood tests*

One-way repeated measures ANOVA showed a significant increase of growth hormone in post hoc test

Table 2. Characteristics of subjects[a]

		LIO group (n = 24)	DBE group (n = 27)	Statistical significance
Gender	Female	16 (66.7%)	18 (68.0%)	
	Male	8 (33.3%)	9 (32.0%)	> 0.99
Age		72.3 ± 4.5	71.0 ± 4.1	0.16
Spouse	Yes	18 (75.0%)	20 (74.0%)	
	No	6 (25.0%)	7 (26.0%)	> 0.99
Familiy composition	Alone	3 (12.5%)	5 (18.6%)	
	Couples	13 (54.2%)	9 (33.3%)	
	With single child	6 (25.0%)	2 (7.4%)	
	With young couples	0	2 (7.4%)	
	With child and grandchildren	2 (8.3%)	8 (29.6%)	
	Others	0	1 (3.7%)	0.45
Chronic Deseases	Yes	18 (75.0%)	16 (64.0%)	
	No	6 (25.0%)	11 (36.0%)	0.76
Self rated health	Good	11 (45.8%)	7 (24.0%)	
	Not so good	12 (50.0%)	20 (76.0%)	
	Bad	1 (4.2%)	0	0.14
History of fall	Yes	11 (45.8%)	6 (20.0%)	
	No	13 (54.2%)	21 (80.0%)	0.06
Difficulties from floor sitting position to standing	Yes	10 (41.7%)	11 (44.0%)	
	No	14 (58.3%)	16 (56.0%)	> 0.99

[a] Data including categorical variables are analyzed by chi-square, and continuous data by t-test.

Table 3. Changes of variables before and after intervention[a,b]

Category of measurements	Variables	LIO group (n = 19)		DBE group (n = 25)		p Value		
		Baseline survey	Follow-up survey	Baseline survey	Follow-up survey	Main effect by group	Main effect by intervention	Interaction
Performance	Reaction time (ms)	509.9 ± 144.6	448.0 ± 66.0	500.3 ± 70.4	475.0 ± 81.2	0.73	0.002	0.18
	TUGT[c] (s)	7.2 ± 1.4	6.1 ± 0.8	6.9 ± 1.4	7.3 ± 1.5	0.22	0.01	< 0.001
	10 m walking time (s)	5.3 ± 0.7	4.8 ± 0.7	5.7 ± 1.2	5.2 ± 0.9	0.09	< 0.001	0.64
	Left maximum step distance (cm)	98.6 ± 25.4	113.9 ± 16.4	99.4 ± 12.6	111.6 ± 13.8	0.19	< 0.001	0.50
	Right maximum step distance (cm)	104.1 ± 14.4	113.2 ± 14.0	101.1 ± 11.3	109.7 ± 12.8	0.30	< 0.001	0.85
	Functional Reach Test	27.8 ± 4.9	30.4 ± 6.0	26.5 ± 6.3	27.6 ± 5.7	0.19	0.01	0.29
Balance	Left leg standing time with open eye (s)	36.0 ± 22.9	38.6 ± 23.1	32.3 ± 19.6	38.6 ± 21.1	0.77	0.03	0.35
	Right leg standing time with open eye (s)	35.8 ± 23.3	23.6 ± 19.6	38.2 ± 23.1	30.8 ± 23.5	0.13	0.09	0.38
Muscle strength	Left knee extension (kg)	21.1 ± 7.4	25.4 ± 8.2	21.4 ± 6.9	20.6 ± 5.8	0.29	0.004	< 0.001
	Right knee extension (kg)	23.1 ± 7.2	24.7 ± 8.1	22.1 ± 6.1	20.9 ± 6.1	0.25	0.70	0.007
	Left grip power (kg)	25.4 ± 6.9	26.7 ± 8.6	25.3 ± 6.4	26.0 ± 7.9	0.85	0.07	0.63
	Right grip power (kg)	26.6 ± 8.1	27.7 ± 9.5	27.0 ± 7.2	27.0 ± 6.8	0.96	0.27	0.26

[a] Values are mean ± SD. Repeated measures ANOVA is used to compare differences between two groups.
[b] "Main effect by group" means that LIO group (n = 19) and DBE group (n = 25) are compared.
[c] Abbreviations: TUGT, Timed Up and Go Test.

Table 4. Biochemical data[a]

	Pre exercise	Post exercise	15 min later	*p* Value (Post hoc test, pre and post)	*p* Value (Post hoc test, pre and 15 min later)
Growth hormone (*n* = 11)	1.8 ± 2.3	11.1 ± 9.6	7.3 ± 7.7	0.010	0.150
Lactic acid (*n* = 11)	10.1 ± 4.3	15.0 ± 4.6	12.2 ± 6.3	0.057	0.053

[a] Values are mean ± SD. One-way repeated measures ANOVA is used.

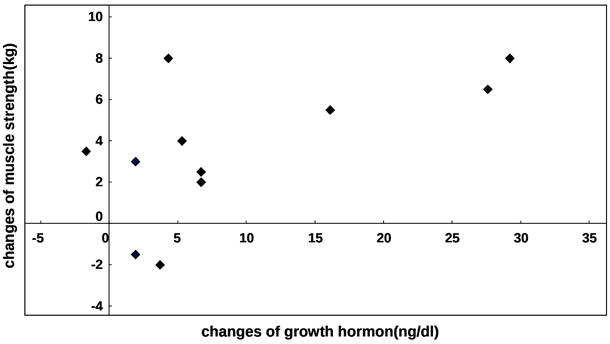

Figure 3. Changes of average knee extensor strength and growth hormone (*n* = 11).

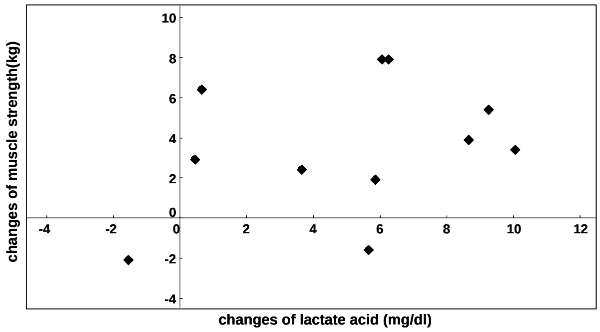

Figure 4. Changes of average knee extensor strength and lactate (*n* = 11).

(p = 0.010) (Table 4). In order to explain the relation between muscle strength and biochemical data, we plotted in scatter diagrams the changes of average knee extensor strength before and after the 8-week program with growth hormone (Figure 3), and with lactate (Figure 4). Correlation coefficient were 0.662 ($p < 0.05$) and 0.163 ($p > 0.05$), respectively. In a 75-year-old male, growth hormone was increased approximately 293 times to that before the training (pre-exercise: 0.1 ng/mL; immediately post-exercise: 29.3 ng/mL). After the 8-week intervention program, left and right knee extension of the male was increased by 58.8% and 22.2%, respectively.

4. Discussion

Although the LIO training has been reported to improve muscular function in young males and athletes and in middle-aged women, there has been no research on its effect in healthy elderly subjects. There were even or significant changes in the measured items, including performance, balance, and muscle strength as compared with DBE program without significant adverse events.

In general, performance is thought to be an integrated ability which is comprised of multiple elements, such as muscle strength, coordination between the central nervous system and muscle, and joint flexibility. There is a report on enhanced performance through resistance training (*14*). In the present study, 6 different exercises were conducted while wearing a pair of special elastic belts. It is possible that the enhancement of performance can be attributed to the improved nerve-and-muscle coordination, resulting in improved muscle strength of the lower limbs (*15*).

The results of the functional reach test and standing on one leg were satisfactory after both LIO and DBE programs. It was likely that the subjects relearned to move the center of gravity and maintain a dynamic posture. Namely, when the subjects performed the forward lunges, they moved the center of gravity back and forth without raising their feet from the floor. In the knee lifts, while repetitively and alternately standing on one of the legs, the subjects maintained their center of gravity within the narrow base of support. Similar to a report investigating the effects of Tai Chi (*16*), such repetitive posture change and the associated improvement in lower-limb strength might have stabilized the range of motion of the center of gravity. Thus, even a short-term LIO could improve balance as effectively as DBE in the elderly.

After the LIO program, left and right knee extension increased by 20.4% and 6.9%, respectively. However, after the DBE program, it decreased slightly by 3.7% and 5.4%, respectively. A difference between the left and right was probably because the participants tended to put an uneven load on both of the legs. Half-squats and forward lunges caused repetitive eccentric and concentric quadriceps contractions. Such local and mechanical stimulation may have been linked with the improvement in muscle strength. Thus, it is certain that even a short-duration and low-intensity LIO training can improve lower-limb muscle strength in the elderly as effectively as resistance machine training in older adults and LIO training in the young athletes (*14,17*). Prior studies have reported an increase in plasma level of growth hormone in young subjects after the LIO (*17,18*). In accordance with these studies, we observed similar increased levels of growth hormone in the elderly.

In the study of Takarada *et al.* (*10*), plasma levels of growth hormone, norepinephrine, and lactate increased remarkably immediately after LIO. Furthermore, LIO had a significant effect equal to or even greater than high-intensity resistance training on an increase in muscular size and strength (*11*). The correlation among LIO, lactate, and growth hormone has been discussed as follows: due to moderate inhibition of muscle blood flow at the time of exercise, lactate as a potential cause of fatigue is produced and accumulates in muscles. Accordingly, even in a low intensity exercise with occlusion, additional motor unit recruitment is required. A large amount of growth hormone essential for muscle synthesis is released from the pituitary gland in the brain and carried by blood circulation throughout the body. Growth hormone delivered to all parts of the body *via* the blood stream is thought to act on muscle tissue, decompose body fat, and produce muscle. In our study, the 8-week LIO program improved physical function, especially muscle strength, which may be associated with the exercise-induced secretion of growth hormone.

The present study had the following limitations: 1) the small samples and short periods did not permit sufficient analysis of the effects on physical function; 2) the results were limited to the case of relatively healthy local elderly residents; and 3) while the results of relatively short-term (8-weeks) trial were obtained, the study could not observe sustained longer-term effects.

This is the first study of LIO designed as a training program targeted at elderly people living in a community. In order to investigate the effects of LIO on physical function, an 8-week LIO program was conducted and compared with an 8-week DBE program. Muscle strength showed a significant increase after the LIO, which may be associated with exercise-induced secretion of growth hormone. This study confirmed that LIO was more effective than DBE in TUGT and muscle strength of knee extension. There were not a large difference of exercise compliance between LIO and DBE, suggesting that LIO could be useful for elderly people. These results suggest that LIO should be seen as one of the most promising physical training programs targeted at healthy elderly people.

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