

The effects of low-intensity resistance training with vascular restriction on leg muscle strength in older men

Murat Karabulut · Takashi Abe · Yoshiaki Sato ·
Michael G. Bemben

Accepted: 10 September 2009 / Published online: 18 September 2009
© Springer-Verlag 2009

Abstract The purpose of this study was to investigate and compare the effects of two types of resistance training protocols on the adaptation of skeletal muscle strength in older men. Thirty-seven healthy male subjects (50–64 years) participated in this study. Subjects were assigned to one of three groups: high-intensity (80% 1-RM) resistance training (RT80); low-intensity (20% 1-RM) resistance training with vascular restriction (VR-RT20); and a control group (CON) that performed no exercise. Subjects in both exercise groups performed three upper body (at 80% 1-RM) and two lower body exercises either with (20% 1-RM) or without (80% 1-RM) vascular restriction three times a week for 6 weeks. As expected, the RT80 and VR-RT20 groups had significantly ($p < 0.01$) greater strength increases in all upper body and leg press exercises compared with CON, however, absolute strength gains for the RT80 and VR-RT20 groups were similar ($p > 0.05$). It should be noted that the percentage increase in leg extension strength for the RT80

group was significantly greater than that for both the VR-RT20 ($p < 0.05$) and CON groups ($p < 0.01$), while the percentage increase in leg extension strength for the VR-RT20 group was significantly ($p < 0.01$) greater than that for the CON. The findings suggested that leg muscle strength improves with the low-load vascular restriction training and the VR-RT20 training protocol was almost as effective as the RT80 training protocol for increasing muscular strength in older men.

Keywords Blood flow restriction · Exercise volume · Strength

Introduction

The age-related declines in muscle mass and strength can be explained by several factors such as a reduction in the size of individual muscle fibers and a loss of fibers (Lexell et al. 1988), inability to fully activate some muscle groups (Enoka et al. 1992), or a decline in the firing rates of motor units (Kamen et al. 1995). However, findings from previous studies have indicated that older individuals can increase skeletal muscle strength (Brown et al. 1990; Frontera et al. 1988; Trappe et al. 2001) in response to resistance training by having adaptations to the neuromuscular system, such as increased motor unit recruitment, improved synchronization of motor units (Enoka 1988; Milner-Brown et al. 1975), and/or reinnervation of denervated muscle fibers (Stalberg et al. 1989).

Häkkinen et al. (2001) reported that the respective increases in maximal isometric and dynamic constant external resistance (DCER) strength of the knee extensors were 28 and 27% in middle-aged men (42 years), 27 and 21% in elderly men (72 years), 27 and 35% in middle-aged

Communicated by Jean-René Lacour, Susan A. Ward.

M. Karabulut (✉)
Department of Health and Human Performance,
University of Texas at Brownsville/Texas Southmost College,
80 Fort Brown, Brownsville, TX 78520, USA
e-mail: murat.karabulut@utb.edu

M. G. Bemben
Department of Health and Exercise Science,
University of Oklahoma, Norman, OK, USA

T. Abe
Graduate School of Frontier Sciences,
University of Tokyo, Chiba, Japan

Y. Sato
Department of Ischemic Circulatory Physiology,
University of Tokyo, Tokyo, Japan

women (39 years), and 26 and 31% in elderly women (67 years) following 6 months of resistance training (50–80% 1-RM). Another study reported that a 10-week resistance training program resulted in increases in isometric squat strength by 23 and 40% in young (30 years) and older (61 years) men, respectively (Newton et al. 2002). Brown et al. (1990) detected a 48% increase in DCER forearm flexion strength of the trained arm in older men (60–70 years) following a 12-week progressive weight training program (50–90% of 1-RM).

Training volume, a combination of the total number of repetitions performed multiplied by the load used, has an effect on the neural and hypertrophic adaptations to resistance training (Kraemer et al. 2002). Training volumes utilizing a moderate to high number of repetitions per set (6–12) at 67–85% 1-RM have been associated with increased skeletal muscle size and strength (Baechle and Earle 2000), however, considerable evidence shows that low-intensity and volume resistance training combined with vascular restriction (VR; also known as KAATSU training) improves muscle strength (Shinohara et al. 1998; Takarada and Ishii 2002; Takarada et al. 2002) to a similar or even a greater extent than traditional resistance training at intensities greater than the 65% 1-RM threshold without VR (Goto et al. 2004, 2005). Following 16 weeks of training, 47–67-year-old women increased isometric elbow flexor strength by 18.4% for the arm performing exercises with VR (at 30–50% 1-RM) and 22.6% for the other arm performing exercises without restriction (at 80% 1-RM) (Takarada et al. 2000b). In a study by Shinohara et al. (1998), young males (mean age = 23.2 years) performed isometric leg extension training (contractions for 2 s and relaxations for 3 s) with partial vascular occlusion at 40% of the isometric maximum voluntary contraction (MVC) for 4 weeks. Isometric leg extension strength increased by 9 and 26% after 2 and 4 weeks of training, respectively. Young male athletes (mean age = 25.6 years) have also been shown to improve their isokinetic strength of the knee extensors by 14% following 8 weeks of training with VR (at ~50% 1-RM) (Takarada et al. 2002).

The majority of previous VR training studies have used an intensity of 20% 1-RM for lower body resistance training exercises in young adults (Abe et al. 2005a, b; Takarada et al. 2000a; Yasuda et al. 2005), however none of the previous published studies examined the effects of low-intensity (at 20% 1-RM) resistance training in combination with VR on lower body skeletal muscle strength in older adults and the only study focusing on older adults investigated the changes in upper body strength in older women (Takarada et al. 2000b). Reducing the volume and relative intensity of resistance training to 20% 1-RM and including VR may be beneficial for individuals that have limited strength or health-related risks associated with

higher resistance training loads and volumes, such as older adults and diseased patients. Therefore, the purpose of this study was to examine and compare the adaptations in the leg muscle strength in older men following a 6-week training program involving low-intensity (20% 1-RM) resistance training with VR (VR-RT20), and a traditional high-intensity (80% 1-RM) resistance exercise training program (RT80). The dependent variables assessed and compared were (a) strength values for upper body and lower body exercises and (b) total volume of the exercises performed for lower body exercises for both training methods. Since previous data showed that low-intensity resistance training in combination with VR was very effective to improve skeletal muscle strength in young adults and older women, it was hypothesized that VR-RT20 training program would be effective to improve skeletal muscle strength in older men.

Methods

Subjects

Thirty-seven healthy older males (ranging in age from 50 to 64 years, mean age = 56.8 ± 0.6 years) participated in this study. Participants were classified as “recreationally active”, which was defined as physically active but not participating in regular structured exercise training. Participants who had a Body Mass Index (BMI) greater than 40 kg/m^2 , were not capable of undergoing physical strength testing and training, or had a history of participation in a regular resistance training program within the last 4 months prior to study were excluded from the study. Participants were asked to obtain medical clearance from their own physicians in order to participate in the research experiment. All training sessions were completed in the lab between September 15 and December 15. Based on power analyses (Cohen 1988), the number of subjects needed for each group ranged from 3 to 5 for all outcome measures to achieve a statistical power >0.80 with an alpha level of $p \leq 0.05$. The study was approved by the University of Oklahoma Institutional Review Board for Human Subjects. All participants were informed of the experimental risks and signed an informed consent document before participation in the study. Each participant also filled out questionnaires, completed pre-testing, and was familiarized with the study procedures during the week before training started.

Procedures

The length of the study was 8 weeks including training, baseline, and post-training testing. Baseline testing and

familiarization with the training procedure took place during the first week and post-testing was completed during the last week of the 8-week period (6 weeks of training). Six different sessions were randomly assigned to either traditional high-intensity or low-intensity training protocols. All qualified participants were asked to choose a session or sessions that they could attend without knowing what session was assigned to what type of exercise protocol. After completion of baseline testing and questionnaires, participants were assigned to either RT80 or VR-RT20 depending on time schedules and subject availability. After completion of training, more participants were recruited and they served as control subjects. The CON group completed pre-testing, were asked to maintain their normal daily activities, then return to the lab 6 weeks later to complete post-testing. Even though the main focus of the study was to investigate and compare the changes in lower body strength between groups, total duration required to complete lower body exercises could be $\sim 2.5\text{--}5$ min (not including rest periods); therefore three upper body exercises were added for the convenience of the participants. The relative exercise intensity for the upper body exercises was the same for both groups throughout the program. Training sessions were preceded by a 5-min standardized warm-up on a cycle ergometer or treadmill. Subjects in the RT80 group performed three upper body (lat pull down, shoulder press, and biceps curl) and two lower body exercises (leg press and leg extension) for three sets of 8 repetitions at 80% 1-RM. Subjects in the VR-RT20 group performed the same upper body exercises at the same intensity (80% 1-RM), but they performed the exercises for lower body with VR for one set of 30 repetitions and 2 sets of 15 repetitions at 20% 1-RM. All sessions were monitored by qualified personnel trained in proper lifting and spotting techniques. Training loads for both exercise groups and for each exercise were adjusted based on 1-RM testing performed every 2 weeks. Total volume of workload for the exercises for each group were calculated with the following equation:

$$\text{Volume} = \text{set} \times \text{total \# of repetitions for each set} \times \text{load}$$

For the VR-RT20 group, the cuffs were placed at the proximal ends of the thigh and inflated before exercises. The cuff pressure was maintained by an electronic air pressure system (KAATSU-Master, Sato Sports Plaza Ltd., Tokyo, Japan). The restrictive pressure used during training was started at 160 mmHg and was adjusted based on ratings of perceived exertion (RPE) obtained after each set during the previous session. The restrictive pressure was increased 20 mmHg for the next training session when RPE was below 16 and kept the same when RPE was between 16 and 19 during the previous training session. The mean restrictive pressure and RPE throughout the period of training were

205.4 ± 4.3 mmHg and 16.5 ± 0.5 (mean \pm SE), respectively. The highest pressure recorded was 240 mmHg. The pressure for VR pressure was decided based on the protocol used in the previous studies investigating the changes in lower body strength in young adults (Abe et al. 2005a; Yasuda et al. 2005). It should be noted that changes in restriction pressure have a potential effect on the magnitude of metabolic challenge due to changes in the amount of blood flow to the lower extremities and venous blood accumulation in the lower extremities. There was a 1-min rest between sets with the cuffs inflated and the cuffs were deflated for about 5–10 min between exercises. The total duration that the cuffs were inflated was <10 min. The post-training testing was performed following the 6-week training period.

One repetition maximum (1-RM) testing

1-RM testing was performed at baseline and every 2 weeks to determine the appropriate training workload and maximum strength for each exercise (lat pull down, biceps curl, shoulder press, leg press, and leg extension) during the training program. Before actual testing, the subjects performed several sub-maximal warm-up trials for each exercise at 50% of their perceived maximal effort. The mass was then increased progressively by 4.5 kg for upper body exercises and by 9 kg for lower body exercises until reaching the maximum mass that could be lifted for one repetition with a 90 s rest interval between each attempt. The 1-RM was determined within four to six trials. These tests were also performed after completion of the training protocol.

Statistical analyses

One way analysis of variance (ANOVA) was used to compare groups at baseline and percent (%) changes from pre- to post-training. Percentage changes were calculated with the following equation:

$$\% \text{ Changes} = \frac{(\text{post} - \text{pre})}{\text{pre}} \times 100.$$

Even though no statistical differences in most of the dependent variables (except for leg press strength) were detected between groups at baseline, a considerable amount of variations in group mean values were detected. Therefore, a one way ANOVA was used to test within subject variation in strength values across time for each group using the Bonferroni-corrected pairwise comparisons. When there were no significant differences between groups at baseline values, two-way repeated measures ANOVA (time [pre vs. post] \times condition [VR-RT20 vs. RT80 vs. CON]) was used to analyze differences between the group means. When

appropriate, post hoc analyses were performed using Bonferroni corrections. When group differences at baseline were detected, analysis of covariance (ANCOVA) was used to account for differences on the particular variable. Since variations in group mean values existed between groups at baseline, ANCOVA was used on all dependent variables at the conclusion of the study. When a significant contribution of the covariate (baseline value) was detected, then the comparison of the data between groups by ANCOVA was reported. All data are expressed as means \pm SE in the text, figures, and tables. An alpha level of $p \leq 0.05$ was considered statistically significant for all comparisons. The data was analyzed using SPSS (SPSS Inc., Chicago, IL, USA) statistical software package.

Results

All trials were completed without injuries, and only 1 subject (from the VR-RT20 group) dropped out during the training program. The overall adherence rate to the training programs in this study was 93% for the VR-RT20 group and 100% for the RT80 group. The baseline characteristics of the thirty-seven healthy older male subjects are presented in Table 1. At baseline, there were no significant differences between groups for age ($p = 0.48$), height ($p = 0.2$), and body mass ($p = 0.79$).

Muscle strength

The only significant difference across groups was for leg press strength by one-way ANOVA ($p < 0.05$, $\eta^2 = 0.25$), however, ANCOVA detected significant contributions of baseline strength measurements as covariates for the lat pulldown, biceps curl, and leg extension exercises. Therefore, ANCOVA was used to account for the variability and to compare the data between groups. Since no significant contribution of baseline strength values for the shoulder press exercise was detected by ANCOVA, two-way repeated measures ANOVA (group \times time) was used

to determine differences within and between groups over time.

Table 2 shows the total training volume for each group throughout the training. The VR-RT20 group lifted 30% less mass for the leg press when compared to the RT80 group ($p < 0.01$, $\eta^2 = 0.40$). Additionally, the VR-RT20 lifted 43% less mass for the leg extension when compared to the RT80 group ($p < 0.01$, $\eta^2 = 0.44$).

Strength values for the lat pulldown ($p < 0.01$, $\eta_p^2 = 0.50$) and biceps curl ($p < 0.01$, $\eta_p^2 = 0.32$) during the training were greater in the VR-RT20 group compared with the RT80 group, but increased in the similar manner (Figs. 1, 3). No significant changes in upper body strength were observed for the CON group. One subject in the CON group did not feel comfortable performing the shoulder press exercise due to a previous shoulder injury; therefore the total number of subjects for the CON group was 10 for the statistical analyses of the shoulder press strength measurements. There was a significant time \times group interaction ($p < 0.01$, $\eta_p^2 = 0.25$) and time effect ($p = 0.01$, $\eta_p^2 = 0.31$) in shoulder press strength, however follow-up tests did not detect any differences between groups (Fig. 2). Strength values increased from baseline significantly starting the fourth or sixth week (post-training) in all muscle groups for both the VR-RT20 and RT80 groups.

Percent (%) changes in upper body strengths from pre- to post-training were significantly greater for both the VR-RT20 ($p \leq 0.01$, $\eta^2 =$ ranged from 0.26 to 0.56) and RT80 ($p \leq 0.04$, $\eta^2 =$ ranged from 0.19 to 0.51) groups compared with the CON group (Fig. 4). There were no significant differences in values between the VR-RT20 and RT80 groups. Percent changes from baseline were 15.9 and 13.2% in lat pulldown strength, 9.6 and 8.6% in shoulder press strength, and 19.3 and 22.9% in biceps curl strength for the VR-RT20 and RT80 groups, respectively.

Strength values for leg press ($p < 0.05$, $\eta_p^2 = 0.45$) and leg extension ($p < 0.05$, $\eta_p^2 = 0.53$) during the training were greater in the VR-RT20 group compared with the RT80 group (Figs. 5, 6). Strength values increased significantly from baseline starting the second week for leg extension and fourth week for leg press for both the VR-RT20 and RT80 groups, but not the CON group. There were no significant differences in leg press strength values between the exercise groups at the end of the study. However, the RT80 group experienced a significantly greater leg extension strength gain following training compared with the VR-RT20 ($p < 0.05$, $d = 0.39$) and CON groups ($p < 0.01$, $d = 1.1$). A significant increase in leg extension strength was observed at post-testing compared with baseline ($p < 0.01$, $\eta_p^2 = 0.43$) for the CON group.

The RT80 and VR-RT20 groups had a significantly greater percentage change from pre- to post-training in

Table 1 Physical characteristics at baseline for each group

Variable	Group		
	VR-RT20 ($n = 13$)	RT80 ($n = 13$)	CON ($n = 11$)
Age (years)	55.9 \pm 1.0	57.5 \pm 0.8	57.0 \pm 1.1
Height (cm)	179.2 \pm 1.6	177.3 \pm 1.7	174.1 \pm 2.5
Weight (kg)	86.5 \pm 3.6	85.1 \pm 4.5	82.4 \pm 4.6

Values are means \pm SE

VR-RT20 low-intensity exercise training with vascular restriction group, RT80 high-intensity traditional resistance training group, CON control group

Table 2 Total volume of workload for leg press and leg extension exercises during 6 weeks of resistance training

Exercise	Training week	VR-RT20 (<i>n</i> = 13)	RT80 (<i>n</i> = 13)	Difference (%)
Leg press (kg)	1–2	8,706 ± 373	11,479 ± 570	–31.8*
	3–4	9,293 ± 372	12,083 ± 616	–30.0*
	5–6	9,923 ± 429	12,822 ± 667	–29.2*
	Total	27,923 ± 1,112	36,386 ± 1,822	–30.3*
Leg extension (kg)	1–2	4,956 ± 258	6,818 ± 413	–37.6*
	3–4	5,480 ± 270	7,783 ± 489	–42.0*
	5–6	5,729 ± 256	8,454 ± 519	–47.6*
	Total	16,167 ± 768	23,055 ± 1,392	–42.6*

Difference (%) = (VR-RT20 – RT80)/VR-RT20 × 100

* Statistically significant difference (*p* < 0.05) between VR-RT20 and RT80. Values reported as mean ± SE

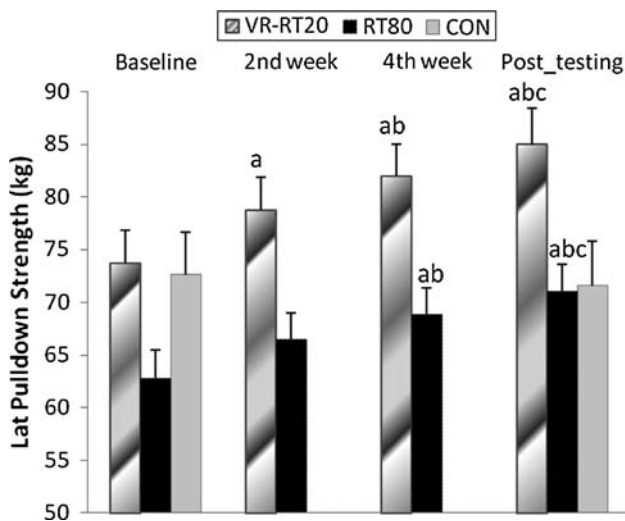


Fig. 1 Lat pulldown strength response to 6 weeks of resistance training. *a* Significantly different (*p* < 0.05) from baseline; *b* significantly different (*p* < 0.05) from second week; *c* significantly different (*p* < 0.05) from fourth week. Values reported as mean ± SE

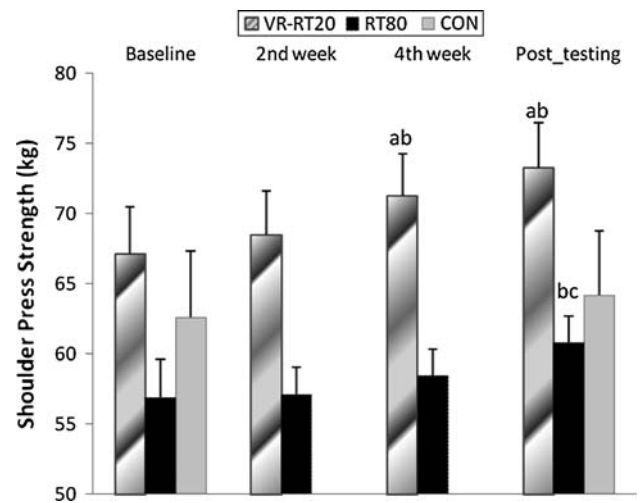


Fig. 2 Shoulder press strength response to 6 weeks of resistance training. *a* Significantly different (*p* < 0.05) from baseline; *b* significantly different (*p* < 0.05) from second week; *c* significantly different (*p* < 0.05) from fourth week. Values reported as mean ± SE

both leg press (*p* < 0.01, *d* = 1.7 and *p* < 0.01, *d* = 1.86, respectively) and leg extension strengths (*p* < 0.01, *d* = 2.56 and *p* < 0.01, *d* = 1.62, respectively) compared with the CON group (Fig. 7). The change in the RT80 group was significantly greater in leg extension compared with the VR-RT20 group (*p* < 0.05, *d* = 0.84), but not leg press. There were 19.3 and 20.4% increases in leg press strength and 19.1 and 31.2% increases in leg extension strength from baseline for the VR-RT20 and RT80 groups, respectively.

Discussion

The current study is the first to compare low-intensity (20% of 1-RM) resistance exercise training in combination with VR and high-intensity (80% of 1-RM) traditional resistance training on muscle strength gains in older men. The data indicated that the VR and traditional resistance training

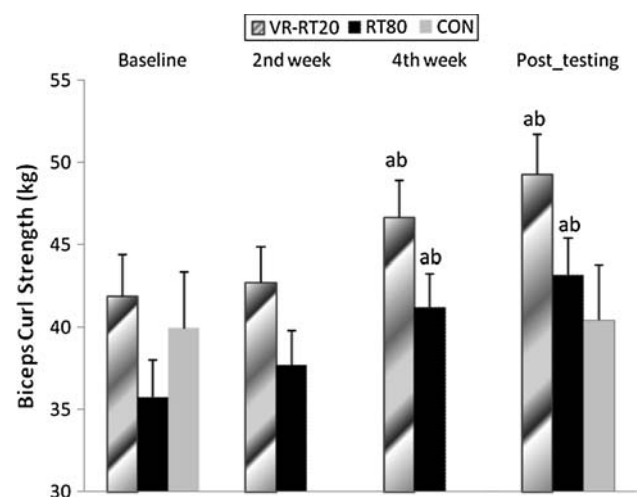


Fig. 3 Biceps curl strength response to 6 weeks of resistance training. *a* Significantly different (*p* < 0.05) from baseline; *b* significantly different (*p* < 0.05) from second week. Values reported as mean ± SE

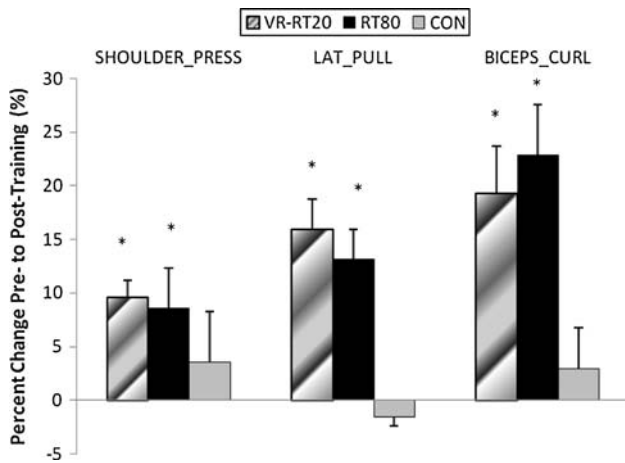


Fig. 4 Shoulder press, lat pulldown, and biceps curl strength percentage change from baseline to the end of the study. *Significantly different ($p < 0.05$) from control. Values reported as mean \pm SE

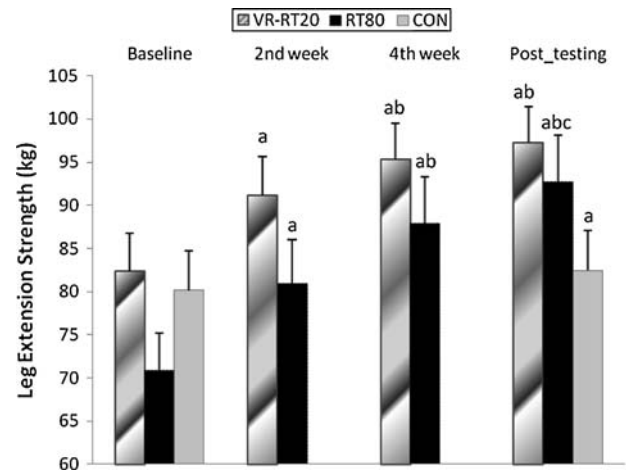


Fig. 6 Leg extension strength response to 6 weeks of resistance training. ^a Significantly different ($p < 0.05$) from baseline; ^b significantly different ($p < 0.05$) from second week; ^c significantly different ($p < 0.05$) from fourth week. Values reported as mean \pm SE

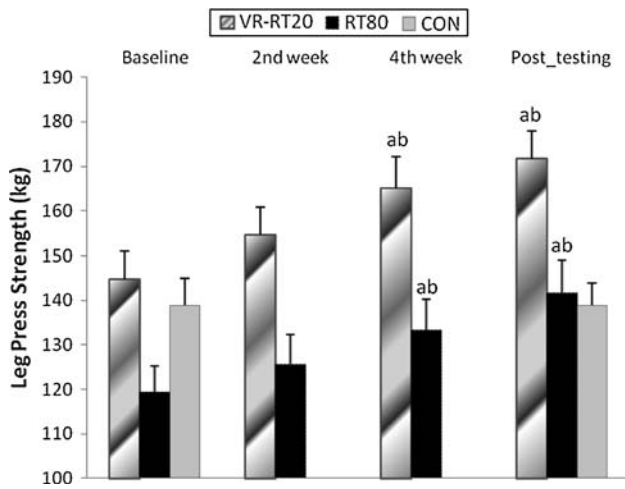


Fig. 5 Leg press strength response to 6 weeks of resistance training. ^a Significantly different ($p < 0.05$) from baseline; ^b significantly different ($p < 0.05$) from second week. Values reported as mean \pm SE

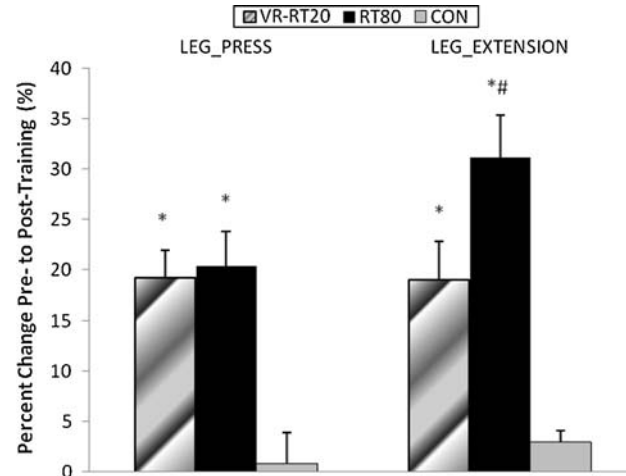


Fig. 7 Leg press and leg extension strength percentage change from baseline to the end of the study. *Significantly different ($p < 0.05$) from control; [#]Significantly different ($p < 0.05$) from VR-RT20. Values reported as mean \pm SE

programs resulted in somewhat similar changes, but not in all dependent variables, which was verified by the increases in 1-RM values for each exercise. Previous studies have reported the effectiveness of traditional resistance training to improve neuromuscular function in older adults (Häkkinen et al. 1996; Newton et al. 2002), but the risk of injury was higher for the elderly (Pollock et al. 1991). Since the VR training technique uses a smaller mechanical load than most conventional resistance training programs, it may be advantageous for older adults. In addition, increases in muscle size in older women following a 16-week resistance training program with VR indicated that a longer period of use of this new training method could potentially increase muscle size in older men.

The findings from the present study were consistent with those from previous studies that reported increases in strength following training in older adults (Häkkinen et al. 1996, 2001). In a 12-week strength training study, exercise intensity progressed from 40 to 50% 1-RM for the first 4 weeks of the training to 60–80% 1-RM for the second 4 weeks of the training to 70–90% 1-RM for the last 4 weeks of the training (Häkkinen et al. 1996). Following training, 1-RM strength of the knee extensor muscles was increased by 19% in bilateral trained subjects and by 13% in unilateral trained subjects. In another 6-month study, a 27% increase in 1-RM strength of the knee extensors (27%) was observed in middle-aged men (Häkkinen et al. 2001). Even though the total training periods of two previous studies (Häkkinen et al.

1996, 2001) were longer than the present study, the intensity of the exercises performed during the last 2 months were very similar with the present study resulting in similar strength adaptations.

Since no previous low-intensity VR (LITVR) research has investigated the training-induced adaptations in older men, it is not possible to compare the findings of the current study with the previous findings for the same gender and age group. Therefore, the findings from the present study were compared with those from one older female study using LITVR training (Takarada et al. 2000b). The data from the present study are in line with the previous findings that reported increases in isokinetic strength of the elbow flexors in older women by 18.4% for the arm performing exercises at 30–50% 1-RM with VR and 22.6% for the other arm performing exercises at 80% 1-RM without restriction for 16 weeks (Takarada et al. 2000b). The control group who performed exercises at 30–50% 1-RM without blood flow restriction experienced a 1% increase in isokinetic strength for the elbow flexors (Takarada et al. 2000b). In addition, the magnitude of strength changes seen in the present study appeared to be comparable to the findings of the present study for biceps curl strength (19 and 23% for the VR-RT20 and RT80 groups, respectively), the LITVR training studies that recruited young males (squat and leg curl 1-RM strength increased by 14 and 9%, respectively) (Yasuda et al. 2005), and athletes (isokinetic knee extension strength increased by 14.3%) (Takarada et al. 2002). The magnitude of the change in strength for older females trained with VR was similar, whereas the amount of changes in strength for young adults trained with VR was less than what was reported in the present study. The greater strength gain in older men when compared to young men might be due to lower starting level of strength for older men resulting in greater strength gains. Differences in training measurement technique, age of the participants, and activity level could be the other factors responsible for the variation in strength changes in response to training.

Severely restricting blood flow or complete occlusion to muscle tissue may draw some concerns as traditional knowledge suggests it may cause necrosis, blood coagulation and reduce endothelial function (Margovsky et al. 1997). However, a previous study demonstrated that low-intensity exercise combined with moderate blood flow restriction has no impact upon blood clotting function as assessed by the changes in fibrin D-dimer and fibrin degradation products after exercise (Fujita et al. 2008). Furthermore, unlike complete blood flow occlusion and reperfusion, moderate restriction of blood flow while performing low-intensity exercise has no effect on the markers of oxidative stress based on the amounts of the plasma lipid peroxide (Takarada et al. 2000a), blood glutathione status and plasma protein carbonyls (Goldfarb et al. 2008), as

well as plasma marker of muscle damage (creatine phosphokinase activity) (Takarada et al. 2000a) following the exercise. In addition, a survey to determine the safety of KAATSU exercise has been conducted and approximately 13,000 people, including age over 70 years, have participated (45.4% male and 54.6% female) (Nakajima et al. 2006). The findings support the notion that low-intensity KAATSU training does not pose any crucial side effects or immediate health concerns among healthy elderly population, however, it should be noted that the possibilities for side effects cannot be denied completely.

Low-volume (e.g., high load, low repetitions, moderate to high number of sets) resistance training protocols have been used for strength training, while high volume resistance training protocols with moderate to heavy loads (70–85% of 1-RM) have been utilized for muscle hypertrophy (Kraemer et al. 2002). However, the new technique used in the current study utilizing lower loads and lower training volumes compared to traditional resistance training resulted in similar changes in lower body skeletal muscle strength as the traditional high-intensity resistance training program. These changes in skeletal muscle strength could be attributed to neuromuscular adaptations such as improved muscle and/or nerve coordination and the recruitment of more fast-twitch fibers and their higher threshold motor units (Karabulut et al. 2007). Moritani et al. (1992) reported that the size principle might not apply to contractions with blood flow restriction by showing significant increases in motor unit firing rate and motor unit spike amplitude during contractions at low intensity (20% 1-RM) in combination with blood flow restriction. It should also be noted that there may be several factors responsible for neuromuscular-related strength changes such as metabolite accumulation (lactic acid, ADP, etc.) and low oxygen supply to the active skeletal muscle causing alteration of motor unit firing rate and recruitment patterns leading to neuromuscular adaptations and increased muscular strength. Goto et al. (2005) examined the effects of subproduct accumulation and metabolic stress on muscular adaptations. Even though the volume and the relative intensity were matched between exercise groups, the group that did not have an additional 30 s rest had greater increases in plasma blood lactate, growth hormone, epinephrine, and norepinephrine levels, resulting in greater increments in the 1-RM strength of the knee extensors (66 vs. 39%) and size (13 vs. 4%). The authors suggested that near-maximal effort may be necessary to maximize the recruitment of motor units, which might be responsible for the greater strength adaptations. It is difficult to determine which factors are more important, since there are close relationships between these various factors. Lifting low-loads will apply less mechanical stress on the knee joints; therefore, this new training method might have some advantages for special populations such as

individuals with joint problems. Future research should go beyond examining the effectiveness of this new technique for healthy adults and investigate whether the new training method can improve skeletal muscle strength and quality of life in special populations.

Overall, the findings of the present study were similar to previous findings in terms of the amount of change in strength. Generally, the present study resulted in greater adaptations in strength compared with previous LITVR studies with young subjects, but the amount of the changes in strength were very similar to the changes observed in one previous LITVR study with older women. Even though more research is required, the findings of the present study indicated that VR-RT20 training was as effective as high-intensity traditional resistance training in terms of the magnitude and pattern of change in muscular strength. Achieving similar improvements in lower body muscular strength with low-loads and volumes might be beneficial for individuals who have limited strength such as older adults; therefore, this new technique might be an alternative training method and might have practical applications to improve lower body skeletal muscle strength in healthy older men.

Acknowledgments The authors would like to thank the participants for their commitment and effort during the study. The authors are also grateful to Lee Gregg and Adrien Ferguson for their help and support during training and Dr. Travis Beck for his editorial suggestions.

References

- Abe T, Beekley MD, Hinata S, Koizumi K, Sato Y (2005a) Day-to-day change in muscle strength and MRI-measured skeletal muscle size during 7 days KAATSU resistance training: a case study. *Int J KAATSU Train Res* 1(2):71–76
- Abe T, Yasuda T, Midorikawa T, Sato Y, Kearns CF et al (2005b) Skeletal muscle size and circulating IGF-1 are increased after two weeks of twice daily “KAATSU” resistance training. *Int J KAATSU Train Res* 1(1):6–12
- Baechle TR, Earle RW (2000) *Essentials of strength training and conditioning*. Human Kinetics, Champaign, pp 412–415
- Brown AB, McCartney N, Sale DG (1990) Positive adaptations to weight-lifting training in the elderly. *J Appl Physiol* 69:1725–1733
- Cohen J (1988) *Statistical power analysis for the behavioral sciences*. Lawrence Erlbaum Associates Inc., Hillsdale, pp 19–39
- Enoka RM (1988) Muscle strength and its development. *New perspectives*. *Sports Med* 6:146–168
- Enoka RM, Fuglevand A, Barreto P (1992) Age does not impair the voluntary ability to maximal activate muscle. In: Draganich L, Wells R, Bechtold J (eds) *Proceedings of the second North American congress in biomechanics*, Chicago, IL, pp 63–64
- Frontera WR, Meredith CN, O’Reilly KP, Knuttgen HG, Evans WJ (1988) Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol* 64:1038–1044
- Fujita T, Brechue WF, Kurita K, Sato Y, Abe T (2008) Increased muscle volume and strength following six days of low-intensity resistance training with restricted muscle blood flow. *Int J KAATSU Train Res* 4:1–8
- Goldfarb AH, Garten RS, Chee PD, Cho C, Reeves GV et al (2008) Resistance exercise effects on blood glutathione status and plasma protein carbonyls: influence of partial vascular occlusion. *Eur J Appl Physiol* 104:813–819
- Goto K, Nagasawa M, Yanagisawa O, Kizuka T, Ishii N, Takamatsu K (2004) Muscular adaptations to combinations of high- and low-intensity resistance exercises. *J Strength Cond Res* 18:730–737
- Goto K, Ishii N, Kizuka T, Takamatsu K (2005) The impact of metabolic stress on hormonal responses and muscular adaptations. *Med Sci Sports Exerc* 37:955–963
- Häkkinen K, Kallinen M, Linnamo V, Pastinen UM, Newton RU, Kraemer WJ (1996) Neuromuscular adaptations during bilateral versus unilateral strength training in middle-aged and elderly men and women. *Acta Physiol Scand* 158:77–88
- Häkkinen K, Kraemer WJ, Newton RU, Alen M (2001) Changes in electromyographic activity, muscle fibre and force production characteristics during heavy resistance/power strength training in middle-aged and older men and women. *Acta Physiol Scand* 171:51–62
- Kamen G, Sison SV, Du CC, Patten C (1995) Motor unit discharge behavior in older adults during maximal-effort contractions. *J Appl Physiol* 79:1908–1913
- Karabulut M, Abe T, Sato Y, Bembem MG (2007) Overview of neuromuscular adaptations of skeletal muscle to KAATSU training. *Int J KAATSU Train Res* 3:1–9
- Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C et al (2002) American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 34:364–380
- Lexell J, Taylor CC, Sjöström M (1988) What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J Neurol Sci* 84:275–294
- Margovsky AI, Lord RS, Chambers AJ (1997) The effect of arterial clamp duration on endothelial injury: an experimental study. *Aust N Z J Surg* 67:448–451
- Milner-Brown HS, Stein RB, Lee RG (1975) Synchronization of human motor units: possible roles of exercise and supraspinal reflexes. *Electroencephalogr Clin Neurophysiol* 38:245–254
- Moritani T, Sherman WM, Shibata M, Matsumoto T, Shinohara M (1992) Oxygen availability and motor unit activity in humans. *Eur J Appl Physiol Occup Physiol* 64:552–556
- Nakajima T, Kurano M, Iida H, Takano H, Oonuma H et al (2006) Use and safety of KAATSU training: results of a national survey. *Int J KAATSU Train Res* 2:5–13
- Newton RU, Häkkinen K, Häkkinen A, McCormick M, Volek J, Kraemer WJ (2002) Mixed-methods resistance training increases power and strength of young and older men. *Med Sci Sports Exerc* 34:1367–1375
- Pollock ML, Carroll JF, Graves JE, Leggett SH, Braith RW et al (1991) Injuries and adherence to walk/jog and resistance training programs in the elderly. *Med Sci Sports Exerc* 23:1194–1200
- Shinohara M, Kouzaki M, Yoshihisa T, Fukunaga T (1998) Efficacy of tourniquet ischemia for strength training with low resistance. *Eur J Appl Physiol Occup Physiol* 77:189–191
- Stalberg E, Borges O, Ericsson M, Essen-Gustavsson B, Fawcett PR et al (1989) The quadriceps femoris muscle in 20–70-year-old subjects: relationship between knee extension torque, electrophysiological parameters, and muscle fiber characteristics. *Muscle Nerve* 12:382–389
- Takarada Y, Ishii N (2002) Effects of low-intensity resistance exercise with short inter-set rest period on muscular function in middle-aged women. *J Strength Cond Res* 16:123–128

- Takarada Y, Nakamura Y, Aruga S, Onda T, Miyazaki S, Ishii N (2000a) Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *J Appl Physiol* 88:61–65
- Takarada Y, Takazawa H, Sato Y, Takebayashi S, Tanaka Y, Ishii N (2000b) Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. *J Appl Physiol* 88:2097–2106
- Takarada Y, Sato Y, Ishii N (2002) Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *Eur J Appl Physiol* 86:308–314
- Trappe TA, Lindquist DM, Carrithers JA (2001) Muscle-specific atrophy of the quadriceps femoris with aging. *J Appl Physiol* 90:2070–2074
- Yasuda T, Abe T, Sato Y, Midorikawa T, Kearns CF et al (2005) Muscle fiber cross-sectional area is increased after two weeks of twice daily KAATSU-resistance training. *Int J KAATSU Train Res* 1(2):65–70