EFFECT OF COMBINED AEROBIC AND RESISTANCE TRAINING WITH BLOOD FLOW RESTRICTION IN THE ELDERLY WOMEN

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Abstract
This study aims to study the effects of concurrent training with blood flow restriction (BFR-CT) and (CT) on the aerobic fitness, muscle mass and muscle strength in a group of older individuals. 25 healthy older adults (64.7 ± 4.1 years; 69.33 ± 10.8 kg; 1.6 ± 0.1 m) were selected as experimental groups: CT (n = 8, endurance training (ET), 2 days/week for 30–40 min, 50–80 % VO2peak and RT, 2 days/week, leg press with 4 sets of 10 reps at 70–80 % of 1-RM with 60 s rest), BFRCT (n = 10, ET, similar to CT, but resistance training with blood flow restriction: 2 days/week, leg press with 1 set of 30 and 3 sets of 15 reps at 20–30 % 1-RM with 60 s rest) or control group (n = 7). Quadriceps cross-sectional area (CSAq), 1-RM and VO2peak were assessed in pre-test and post-test (12 wk). The CT and BFR-CT showed similar increases in CSAq post-test (7.3 %, P < 0.001; 7.6 %, P < 0.0001, respectively), 1-RM (38.1 %, P < 0.001; 35.4 %, P = 0.001, respectively) and VO2peak (9.5 %, P = 0.04; 10.3 %, P = 0.02, respectively). The BFR-CT develops similar neuromuscular and cardiorespiratory adaptations as CT.

INTRODUCTION

Aging causes a progressive decrease in aerobic fitness, strength and muscle mass [2]. These reductions are related to the increased incidence of type 2 diabetes [11], cardiovascular disease [30] and the risk of deaths due to accidents like falls [7]. Regarding this, it is widely recommended that both resistance (RT) and endurance (ET) training be combined due to its positive effects on the maintenance and/or increase in skeletal muscle mass and strength, and in aerobic fitness [2, 4]. According to the present guidelines it can be understood that to improve the function of the cardiovascular and neuromuscular systems,the ET and RT should be performed with intensities of ≥ 60 % of the maximal oxygen consumption (VO2max) and ≥ 60 % of the 1-RM load (high-intensity RT), respectively[2, 4]. However, some studies proved that the relationship between high-intensity RT (HIRT) and ET (i. e. concurrent training – CT) can disrupt the increasing of muscle mass in elderly [17, 29], this has been referred to as the interference phenomenon [6]. Accordingly, Sillanpää et al. [29] reported that in elderly who performed 21 weeks of RT, there has been an increase in lower-limb muscle mass, and not in those who undertook a CT program.
In a more recent study, Karavirta et al. [17] did not find any increase in type II fiber CSA when RT sessions were alternated with ET. While, Izquierdo et al. [13] found an increase in muscle mass in elderly group undergoing CT. Significantly, CT volume dropped to a lower total volume of HI-RT (i. e. sets x repetitions x load) weekly [13]. Therefore, there is a crucial need for strategies to reduce the total volume of RT while maintaining its adaptive potential during a combined ET and RT program (CT program). Several studies indicated that low-intensity RT (20 % 1-RM) combined with partial blood flow restriction (BFR-RT) is useful at inducing similar gains in muscle strength and mass in comparison with conventional HI-RT (80 % 1-RM) [20, 21].

The low intensity of this training methods seems equivalent to those in activities of daily life (10-30 % of maximal work capacity) [1]. This low intensity approach additionally results in a lower risk of injury in comparison with conventional HI-RT, mainly for the elderly [16, 28]. Significantly, the lower intensity existent in BFR-RT also makes the total volume of RT decrease, this has been considered as an important factor inhibiting the CT induced interference phenomenon. Thus, it seems reasonable to hypothesize that the association of BFR-RT with ET may dull the interference phenomenon observed after CT protocols, comprising an interesting and alternative approach to exercise aiming to increase aerobic fitness, muscle mass and strength compared to regular CT. Therefore, the present study aimed to study the effects of an exercise training program associating ET and BFRRT (i. e. BFR-CT) compared to the traditional CT approach (ET + HI-RT) on aerobic fitness, muscle mass and muscle strength among a comrade of older individuals. We hypothesized that only the BFR-CT would cause muscle hypertrophy. An additional hypothesis was that both the BFR-CT and CT would induce increases in aerobic fitness and muscle strength, similarly.

METHODS

25 older individuals (over 60 years of age) took part as volunteers in this study. Inclusion criteria were as follows: a) being inactive or irregularly active according to the international questionnaire of physical activity level [8]; b) having no cardiovascular and neuromuscular disorders and; c) not being considered as obese (BMI > 30 kg · m2). The participants were categorized into quartiles according to their muscle strength and CSAq. Participants from each quartile were then randomly put in one of the following groups: concurrent training group (CT, n = 8, age = 65 ± 3.7 years, weight = 68.2 ± 8.1 kg, height = 1.66 ± 0.1 m, BMI = 24.8 ± 2.6 kg · m2), concurrent training with moderate blood flow restriction (BFR-CT, n = 10, age = 64 ± 4 years, weight = 70.3 ± 8.0 kg, height = 1.63 ± 0.1 m, BMI = 26.3 ± 3.0 kg · m2) and control group (CG, n = 7, n = 8, age = 65 ± 4 years, weight = 69.2 ± 15.1 kg, height = 1.61 ± 0.1 m, BMI = 26.6 ± 4.4 kg · m2). A one-way ANOVA ensured an almost zero level of the between-group differences ($P > 0.05$) in the pre-training VO2peak, muscle strength and CSAq values. The study was done in accordance with the Declaration of Helsinki, and ethical approval was granted by the ethics committee of the local university. Our study was in accordance with the ethical standards of the International Journal of Sports Medicine [12]. This study aimed to investigate the efficacy of an alternative training model in which older individuals performed BFR-RT instead of regular HI-RT in combination with ET. Before the experimental protocol, quadriceps cross sectional area (CSAq) was gained through magnetic resonance imaging (MRI). Afterwards, the participants enlisted into 2 familiarization sessions to get familiarized with the training protocol and testing procedures. Seventy two hours after the last familiarization session, the participants were asked to perform a leg press one-repetition maximum test (1-RM) and a VO2max test. Participants were then categorized into one of the following groups: a) regular concurrent training group (CT: combination of HI-RT and ET); b) blood-flow restriction CT group (BFR-CT: combination of BFR-RT and ET) and; c) control group (CG). Training was done 4 days weekly (Monday and Thursday – RT and Tuesday and Friday – ET) for 12 weeks. The CSAq, leg press 1RM, and VO2peak were reevaluated after the experimental period. The 1-RM and VO2peak were also studied at mid-point (i. e. after 6 weeks of intervention) to adjust the training load. The participants were asked to perform a maximum graded exercise test on a treadmill (Quinton TM55, Bothell, Washington, EUA). Using an automated breath-by-breath metabolic system (CPX, Medical Graphics, St. Paul, Minnesota, USA), gas exchange data were constantly collected [23]. The protocol consisted of a 2-min warm-up at 4 km · h−1, then increases were shown in increments of 0.3 km · h−1 every 30 s until exhaustion. A 1 % grade was used to reproduce athletic track conditions [14]. The highest 30 s mean oxygen consumption value was defined as the peak oxygen consumption (VO2peak), as no VO2 plateau was seen in any of the individuals. 3 experienced researchers detected the ventilator threshold (VT) and respiratory compensation point (RCP) by standard visual analysis [26].

The criteria were described by the procedures for the 45 ° leg press 1-RM test which was followed previously [5]. In a nutshell, participants were asked to perform a general warm-up on a cycle ergometer at 20 km · h − 1 for 5 min, and then a set of specific warm-ups of 45 ° leg press exercise. In the first set, individuals were asked to perform 8 repetitions with a load corresponding to 50 % of their estimated 1-RM, obtained during the familiarization sessions. In the second set, they were asked to perform 3 repetitions at 70 % of their estimated 1RM. A 2-min interval was allowed between warm-up sets. Having done warming-up, the participants performed the leg-press 1-RM test protocol. First, they sit in the machine and then both their feet were placed in a self-selected position. The area of the leg press platform was divided into 10-cm squares to keep record of the feet location, which was reproduced thereafter. The machine was then unlocked, and the platform was lowered to obtain a relative knee angle of 90 ° (i. e. measured with a manual goniometer). Fixing a plastic device on the sliding track of the machine, the displacement of the leg press platform was reproduced in each trial. The repetition started at complete knee extension, and participants were asked to lower the platform until it touched the plastic device and then were returned to full extension. Participants were asked to perform up to 5 attempts to achieve an estimation of the leg press 1-RM. A 3-min interval was enforced between attempts.

Quadriceps cross-sectional area (CSAq) was obtained through magnetic resonance imaging (MRI) (Signa LX 9.1, GE Healthcare, Milwaukee, WI, USA). Participants laid on the device in supine position with their knees extended. To confine leg movements during image acquisition Velcro stripes were used. To determine the perpendicular distance from the greater trochanter to the inferior border of the lateral epicondyle of the femur, defined as the segment length, an initial image was captured. CSAq image was obtained at 50 % of the segment length in 0.8 cm slices for 3 s. The pulse sequence was conducted with a view field between 400 and 420 mm, time repetition of 350 ms, eco time from 9 to 11 ms, 2 signal acquisitions, and matrix of reconstruction of 256 × 256. To determine CSAq, the images were transferred to a workstation (Advantage Workstation 4.3, GE Healthcare, Milwaukee, WI, USA). The segment slice was divided into skeletal muscle, subcutaneous fat tissue, bone, and residual tissue. CSAq was finally evaluated by computerized planimetry on 2 different days, 72 h apart (Typical error 0.36 cm2, 1.69 %).

The ET protocol was the same between the 2 training groups. The RT in the BFR-CT group included of 1 × 30 repetitions and 3 × 15 repetitions 20 % 1-RM associated with partial blood-flow restriction (i. e. BFR-RT) in the leg press exercise. After the 6^{th} week of training, the exercise was intensified to 30 % 1-RM. A 1-min rest interval was taken between sets. Participants trained with an air cuff were placed at the inguinal fold, and throughout the training session (50 % of the complete occlusion pressure) including the rest intervals, a moderate blood-flow restriction was sustained. There were no adverse effects from the blood flow restriction protocol (e. g., excessive fatigue or pain) observed by any of the participants.

Data are presented as mean ± standard deviation. Data normality and variance equality were evaluated through the Shapiro-Wilk and Levene tests. A mixed model, with group and time as fixed factors and subjects as a random factor, was applied for the analysis of total volume of RT (sets x repetitions x load) and volume of ET (distance in meters), VO2peak, leg press 1-RM, and CSAq. A Tukey adjustment was used for multiple comparison purposes in case of significant F-values. The significance level was set at $P < 0.05$.

RESULTS

Training volume

Table 1 illustrates the difference in training volume between the two training groups. Total RT volume (sets x repetitions x load) in the BFR-CT was lower than that of in the CT group (41 % from week 1 to 6, $P = 0.02$ and 34 % from week 7 to 12, $P = 0.02$). There were no significant differences in ET volume between the 2 groups ($P > 0.05$). Both groups showed a significant increase in ET (CT:
43.1 % and BFR-CT: 49.7 %; $P < 0.0001$) and RT (CT: 40.5 % and BFR-CT: 69.6 %, $P < 0.0001$) volumes during the training period (when comparing weeks 1–6 and 7–12).

Peak oxygen uptake (VO2peak)

The CT and BFR-CT groups showed a significant increase in VO2peak from pre- to post-test (9.5 %, $P = 0.04$ and 10.3 %, $P = 0.02$, respectively) (Fig. 1). There were no significant differences in VO2peak values between groups at the post-test ($P > 0.05$). Also no significant difference was observed in VO2peak from pre- to posttest in the CG (– 1.1 %, $P > 0.05$).

Maximum dynamic strength test (1-RM)

Both the CT and BFR-CT groups showed an increased leg press 1-RM values from pre- to post-test (38.1 %, $P < 0.001$ and 35.4 %, respectively; $P = 0.001$) (Fig. 2), there were no differences between the 2 groups at post-test ($P > 0.05$). No significant changes were detected in leg press 1-RM for the CG from pre- to posttest (– 4.3 %, $P > 0.05$).

Quadriceps cross-sectional area (CSAq)

The CT and BFR-CT groups showed increased significantly in CSAq from pre- to post-test (7.3 %, $P < 0.0001$ and 7.6 %, $P < 0.0001$, respectively) (Fig. 3). There were between-group differences in the post-test ($P > 0.05$). Also no compelling difference was seen in CSAq from pre- to post-test in the CG (– 2.2 %, $P > 0.05$).

DISCUSSION

To improve aerobic fitness, strength, and muscle mass in the elderly, the American College of Sports Medicine suggests performing endurance training (ET) and high-intensity resistance training (HI-RT) simultaneously[2, 4]. As an alternative model to the traditional recommendation (i. e. ET + HI-RT), the present study aimed to investigate the effects of ET in combination with low-intensity RT related to partial blood-flow restriction (RT-BFR) [2]. The main findings of the present study indicated a similar improvement between the VO2peak, muscle strength and CSAq between the 2 training methods.

Regarding the improvements in aerobic fitness, our data confirm the previous findings that have shown increases in VO2peak after traditional CT (i. e. ET combined with HI-RT) [17, 29]. Similarly, Karavirta et al. [17] increased by 10 % in VO2peak after 21 weeks (40–90 min of ET at an intensity with an aerobic and anaerobic threshold) of CT. In this study, both the CT and BFR-CT groups showed a similar ET intensities (60–85 % VO2peak) and volumes (60 min, ~4245.7 m per session), generating comparable improvements in VO2peak (9.5 and 10.3 %, respectively). These findings support the inclusion of ET that is associated with either HI-RT or BFR-RT in exercise training routines targeted at improving aerobic fitness in the elderly. This is of great significance as older individuals showing higher VO2peak values are at a lower risk of developing metabolic syndrome [15, 35], diabetes [18] and cardiovascular diseases [19]. Muscle strength has also decreased with aging [9]. In this regard, HI-RT (i. e. ≥ 60 % 1-RM) has been widely suggested to compensate for some of the age-related loss in muscle function [2]. Previous studies showed similar increases in muscle strength after traditional CT in comparison with isolated HI-RT in older adults [17, 29]. For instance, Sillanpää et al. [29] indicated similar increases in lower-limb muscle strength after 21 weeks of either CT or HI-RT (17 and 15 %, respectively). In this study, a similar increase was also detected in muscle strength between the CT (38.1 %) and BFR-CT (35.4 %) groups. Significantly, the BFR-CT group, compared to the CT group, pursued lower-intensity RT as well as lower total volume of RT. This may be caused by fatigue in BFR-RT during BFR-CT, which can result in an increase in the recruitment of muscle fibers, in particular type II fibers [31–33]. Suga et al. [31] indicated that the recruitment of fast-twitch fiber, assessed by Pi-splitting, was due to supplementing the low-intensity resistance exercise with blood flow restriction. Additionally, the study also indicated that recruitment of fast fibers in BFR-RT was similar to HI-RT [31]. The mechanism through which fatigue increases the recruitment of motor units is not well understood. It is recommended that the partial restriction of blood flow during RT results in inadequate oxygen supply to the active skeletal muscle [34], which causes increased metabolite accumulation and decreased intramuscular pH. Consequently this cause an altered motor unit firing rate and recruitment patterns [32], which results in neuromuscular adaptations and increased muscle strength.

The reduction in functionality caused by aging is also related to a progressive decline in muscle mass [22]. Adults are reported to lose only 5–10 % of muscle mass from ages 20 to 50. However, losses increase from the ages 50 to 80, by 30–40 % [22]. To minimize losses and also to improve muscle hypertrophy, HI-RT has been highly suggested [2– 4]. However, HI-RT being associated with ET (i. e. CT), impairments in muscle hypertrophy are predicted to occur [17, 29]. This interference phenomenon appears to be related to greater total volumes of HI-RT. In this respect, Izquierdo et al. [13] reported a significant rise in muscle mass after a low-volume HI-RT + ET training. In this study, total RT volume differs with different conditions. The BFR-CT showed a decrease in total volume of RT in comparison with CT group. However, opposed to our initial hypothesis, both training methods showed an equal effectiveness in increasing muscle mass in the elderly (BFR-CT: 7.6 % and CT: 7.3 %). Disregarding the fact that the total volume of RT was higher by ~37.5 % in the CT than that of in the BFR-RT group, it was still lower than those shown in previous studies with a blunted hypertrophy response while combining HI-RT and ET in older individuals [17, 29]. It is therefore possible that a low total volume of either HI-RT or BFR-RT is necessary to avoid the interference phenomenon associated with ET. Although both training methods have shown similar results, the lower lifting loads applied in the BFR-CT groups causes less mechanical stress on the knee joints, which may result in an interesting advantage for the elderly, particularly those with joint problems. The equipment applied in our BFR-model is an adapted sphygmomanometer that has the capability of restricting the thigh blood flow. Therefore, this simple and inexpensive device may be useful in health clubs, fitness clubs, and so on. The fact that a couple large-scale studies have affirmed the safety of BFR-RT method, even for the elderly [25, 27, 36], supports this suggestion. Evidenced by the small decrease in muscle function and increase in muscle soreness after its execution, muscle damage caused by BFR-RT additionally appears to be minimal [24]. Minimization of these 2 factors can be crucially important for the elderly, because it helps to the maintenance of daily life activities without increased risk of injury due to falls caused fatigue and muscle weakness.

Finally, we concluded that aerobic fitness, strength, and muscle hypertrophy were increased in a similar way after the combination of ET with either HI-RT (traditional CT) or BFR-RT (BFR-CT). Our findings indicate that BRF-CT can be an effective alternative approach to the current recommendations in terms of exercise prescription for the elderly.

References

1. *Abe T*, *Kearns CF*, *Sato Y*. Muscle size and strength are increased following walk training with restricted venous blood flow from the leg muscle, Kaatsu-walk training. J Appl Physiol 2006; 100: 1460–1466
2. *ACSM. American College of Sports Medicine position stand*. Exercise and physical activity for older adults. Med Sci Sports Exerc 2009; 41: 1510–1530
3. *ACSM. American College of Sports Medicine position stand*. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009; 41: 687–708

4. *ACSM. American College of Sports Medicine position stand*. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc 2011; 43: 1334–1359
5. *Brown LE*, *Weir JP*. ASEP procedures recommendation I: accurate assessment of muscular strength and power. J Exerc Physiol Online 2001; 4: 1–21
6. *Docherty D*, *Sporer B*. A proposed model for examining the interference phenomenon between concurrent aerobic and strength training. Sports Med 2000; 30: 385–394
7. *Fiatarone MA*, *O'Neill EF*, *Ryan ND*, *Clements KM*, *Solares GR*, *Nelson ME*, *Roberts SB*, *Kehayias JJ*, *Lipsitz LA*, *Evans WJ*. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994; 330: 1769–1775
8. *Florindo AA*, *Latorre MRDO*. Validação e reprodutibilidade do questionário de Baecke de avaliação da atividade física habitual em homens adultos. Rev Bras Med Esp 2003; 9: 121–128
9. *Frontera WR*, *Hughes VA*, *Fielding RA*, *Fiatarone MA*, *Evans WJ*, *Roubenoff R*. Aging of skeletal muscle: a 12-yr longitudinal study. J Appl Physiol 2000; 88: 1321–1326
10. *Gualano B*, *Ugrinowitsch C*, *Neves M Jr*, *Lima FR*, *Pinto AL*, *Laurentino G*, *Tricoli VA*, *Lancha AH Jr*, *Roschel H*. Vascular occlusion training for inclusion body myositis: a novel therapeutic approach. J Vis Exp 2010
11. *Guillet C*, *Boirie Y*. Insulin resistance: a contributing factor to agerelated muscle mass loss? Diabetes Metab 2005; 31: S20–S26
12. *Harriss DJ*, *Atkinson G*. Ethical standards in sport and exercise science research: 2014 update. Int J Sports Med 2013; 34: 1025–1028
13. *Izquierdo M*, *Ibanez JKHA*, *Kraemer WJ*, *Larrion JL*, *Gorostiaga EM*. Once weekly combined resistance and cardiovascular training in healthy older men. Med Sci Sports Exerc 2004; 36: 435–443
14. *Jones AM*, *Doust JH*. A 1 % treadmill grade most accurately reflects the energetic cost of outdoor running. J Sports Sci 1996; 14: 321–327
15. *Jurca R*, *Lamonte MJ*, *Barlow CE*, *Kampert JB*, *Church TS*, *Blair SN*. Association of muscular strength with incidence of metabolic syndrome in men. Med Sci Sports Exerc 2005; 37: 1849–1855
16. *Karabulut M*, *Abe T*, *Sato Y*, *Bemben MG*. The effects of low-intensity resistance training with vascular restriction on leg muscle strength in older men. Eur J Appl Physiol 2010; 108: 147–155
17. *Karavirta L*, *Hakkinen A*, *Sillanpaa E*, *Garcia-Lopez D*, *Kauhanen A*, *Haapasaari A*, *Alen M*, *Pakarinen A*, *Kraemer WJ*, *Izquierdo M*, *Gorostiaga E*, *Hakkinen K*. Effects of combined endurance and strength training on muscle strength, power and hypertrophy in 40-67-year-old men. Scand J Med Sci Sports 2011; 21: 402–411
18. *Laaksonen DE*, *Lindstrom J*, *Tuomilehto J*, *Uusitupa M*. Increased physicalactivity is a cornerstone in the prevention of type 2 diabetes in high-risk individuals. Diabetologia. 2007; 50: 2607–2608 author reply 2609-2610
19. *Laaksonen DE*, *Niskanen L*, *Lakka HM*, *Lakka TA*, *Uusitupa M*. Epidemiology and treatment of the metabolic syndrome. Ann Med 2004; 36: 332–346
20. *Laurentino G*, *Ugrinowitsch C*, *Aihara AY*, *Fernandes AR*, *Parcell AC*, *Ricard M*, *Tricoli V*. Effects of strength training and vascular occlusion. Int J Sports Med 2008; 29: 664–667
21. *Laurentino GC*, *Ugrinowitsch C*, *Roschel H*, *Aoki MS*, *Soares AG*, *Neves M Jr*, *Aihara AY*, *DARCF A*, *Tricoli V*. Strength training with blood flow restriction diminishes myostatin gene expression. Med Sci Sports Exerc 2012; 44: 406–412
22. *Lexell J*. Human aging, muscle mass, and fiber type composition. J Gerontol A Biol Sci Med Sci 1995; 50: S11–S16
23. *Libardi CA*, *De Souza GV*, *Cavaglieri CR*, *Madruga VA*, *Chacon-Mikahil MP*. Effect of resistance, endurance, and concurrent training on TNFalpha, IL-6, and CRP. Med Sci Sports Exerc 2012; 44: 50–56
24. *Loenneke JP*, *Thiebaud RS*, *Abe T*. Does blood flow restriction result in skeletal muscle damage? A critical review of available evidence. Scand J Med Sci Sports 2014
25. *Loenneke JP*, *Wilson JM*, *Wilson GJ*, *Pujol TJ*, *Bemben MG*. Potential safety issues with blood flow restriction training. Scand J Med Sci Sports 2011; 21: 510–518
26. *McLellan TM*. Ventilatory and plasma lactate response with different exercise protocols: a comparison of methods. Int J Sports Med 1985; 6: 30–35
27. *Nakajima T*, *Kurano M*, *Iida H*, *Takano H*, *Oonuma H*, *Morita T*, *Meguro K*, *Sato Y*, *Nagata T*. Use and safety of KAATSU training: results of a national survey. Int J Kaatsu Training Res 2006; 2: 5–14
28. *Pollock ML*, *Carroll JF*, *Graves JE*, *Leggett SH*, *Braith RW*, *Limacher M*, *Hagberg JM*. Injuries and adherence to walk/jog and resistance training programs in the elderly. Med Sci Sports Exerc 1991; 23: 1194–1200

29. *Sillanpää E*, *Hakkinen A*, *Nyman K*, *Mattila M*, *Cheng S*, *Karavirta L*, *Laaksonen DE*, *Huuhka N*, *Kraemer WJ*, *Hakkinen K*. Body composition and fitness during strength and/or endurance training in older men. Med Sci Sports Exerc 2008; 40: 950–958
30. *Strait JB*, *Lakatta EG*. Aging-associated cardiovascular changes and their relationship to heart failure. Heart Fail Clin 2012; 8: 143–164
31. *Suga T*, *Okita K*, *Morita N*, *Yokota T*, *Hirabayashi K*, *Horiuchi M*, *Takada S*, *Omokawa M*, *Kinugawa S*, *Tsutsui H*. Dose effect on intramuscular metabolic stress during low-intensity resistance exercise with blood flow restriction. J Appl Physiol 2010; 108: 1563–1567
32. *Suga T*, *Okita K*, *Morita N*, *Yokota T*, *Hirabayashi K*, *Horiuchi M*, *Takada S*, *Takahashi T*, *Omokawa M*, *Kinugawa S*, *Tsutsui H*. Intramuscular metabolism during low-intensity resistance exercise with blood flow restriction. J Appl Physiol 2009; 106: 1119–1124
33. *Takarada Y*, *Takazawa H*, *Sato Y*, *Takebayashi S*, *Tanaka Y*, *Ishii N*. Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. J Appl Physiol 2000; 88: 2097–2106
34. *Tanimoto M*, *Madarame H*, *Ishii N*. Muscle oxygenation and plasma growth hormone concentration during and after resistance exercise: Comparison between "KAATSU" and other types of regimen. Int J KAATSU Training Res 2005; 1: 51–56
35. *Wijndaele K*, *Duvigneaud N*, *Matton L*, *Duquet W*, *Thomis M*, *Beunen G*, *Lefevre J*, *Philippaerts RM*. Muscular strength, aerobic fitness, and metabolic syndrome risk in Flemish adults. Med Sci Sports Exerc 2007; 39: 233–240
36. *Yasuda T*, *Fukumura K*, *Fukuda T*, *Uchida Y*, *Iida H*, *Meguro M*, *Sato Y*, *Yamasoba T*, *Nakajima T*. Muscle size and arterial stiffness after blood flow-restricted low-intensity resistance training in older adults. Scand J Med Sci Sports 2014; 24: 799–806