Optimizing strength training for hypertrophy

- A periodization of classic resistance training and blood-flow restriction training

Daniel Cortobius and Niklas Westblad

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Supervisor: Niklas Psilander
Examinator: Pia Lundquist Wanneberg

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Abstract

Aim

The main aim of this study was to investigate if a combination of classic resistance training and blood flow restricted resistance exercise (BFRE) training would result in greater increases in quadriceps muscle growth compared with other strength training studies. The second aim was to investigate if there would be any difference in muscle hypertrophy between men and women after the training intervention.

Method

Twenty untrained subjects (10 males and 10 female) were recruited to participate in a 10-week unilateral resistance training intervention. Sixteen subjects completed the training intervention. After two familiarization sessions subjects performed three sessions per week in leg press and leg extension, except for week 4 and 8 were subjects performed five BFRE training sessions Monday to Friday. All subjects performed a one repetition maximum test in leg press and leg extension pre and post the training intervention. Ultrasound screening was performed pre and post training intervention to measure muscle thickness in m. vastus lateralis (VL).

Results

The 10-week intervention resulted in a significant increase of VL muscle thickness by 15,1 % ± 7,6 ($p \leq 0{,}01$). Both men and women increased in VL muscle thickness, men (n=7) by 15,4 % ± 9,3 ($p \leq 0{,}01$) and women (n=9) by 14,8 % ± 6,0 ($p \leq 0{,}01$), with no difference between genders. Maximal strength increased for the entire group in the leg press by 59,1 % ± 27,4 ($p \leq 0{,}01$) and in the leg extension by 19,8 % ± 13,1 ($p \leq 0{,}01$). Men had an increase of 58,1 % ± 18,0 ($p \leq 0{,}01$) and women with 60,3 % ± 32,8 ($p \leq 0{,}01$) in the leg press. In the leg extension women and men increased their maximal strength by 23,3 % ± 7,4 ($p \leq 0{,}01$) respectively 17,0 % ± 14,4 ($p = 0{,}051$).

Conclusions

Our unique training protocol resulted in a superior increase in muscle growth in comparison with most other strength training studies. Our result can be converted to an increase of 17,3 % (0,25 % per day) in VL muscle CSA, which is much greater than the mean increase of 0,11 % per day reported in a large meta-analysis (Wernbom, Augustsson & Thomeé 2007).

Sammanfattning

Syfte och frågeställningar

Huvudsyftet med denna studie var att undersöka om en kombination av klassisk styrketräning och blodrestriktionsträning (BRFE) skulle resultera i större muskelökning av quadricepsmuskulaturen jämfört med andra styrketräningsstudier. Det andra syftet med denna studie var att undersöka om det var någon skillnad i muskelökningen mellan män och kvinnor efter träningsinterventionen.

Metod

Tjugo otränade försökspersoner (FP) (10 män och 10 kvinnor) rekryterades för att delta i en 10 veckor unilateral-styrketräningsintervention. Sexton FP genomförde hela träningsinterventionen. Efter två tillvänjningspass genomförde FP tre träningspass per vecka i benpressen och bensparken, med undantag för vecka 4 och 8 då FP genomförde fem träningspass, måndag till fredag. Alla FP genomförde ett maximalt test i benpress och benspark före och efter träningsinterventionen. Ultraljudsundersökning genomfördes före och efter träningsinterventionen för att mäta muskeltjocklek av m. vastus lateralis (VL).

Resultat

Den 10 veckor långa träningsinterventionen resulterade i en signifikant ökning i VL muskeltjocklek för hela gruppen 15,1 % ± 7,6 ($p \leq 0{,}01$). Både män och kvinnor ökade i VL muskeltjocklek, män (n=7) med 15,4 % ± 9,3 ($p \leq 0{,}01$) och kvinnor (n=9) med 14,8 % ± 6,0 ($p \leq 0{,}01$), med ingen skillnad mellan könen. Den maximala styrkan ökade för hela gruppen i benpress med 59,1 % ± 27,4 ($p \leq 0{,}01$) och i benspark med 19,8 % ± 13,1 ($p \leq 0{,}01$). Män ökade med 58,1 % ± 18,0 ($p \leq 0{,}01$) och kvinnor med 60,3 % ± 32,8 ($p \leq 0{,}01$) i benpress. I bensparken ökade kvinnor och män sin maximala styrka med 23,3 % ± 7,4 ($p \leq 0{,}01$) respektive 17,0 % ± 14,4 ($p = 0{,}051$).

Slutsats

Vårat unika träningsprogram resulterade i större ökningar i muskelhypertrofi än de flesta andra styrketräningsstudier. Resultatet i muskeltjocklek kan räknas om till tvärsnittsarea vilket ger en ökning av 17,3 % (0,25 % per dag), en ökning som är mycket större än genomsnittet på 0,11 % per dag som rapporterats i en stor meta-analys (Wernbom, Augustsson & Thomeé 2007).

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1 Introduction

Resistance training, or strength training, has become essential for elite athletes to optimize their performance. It is also more frequently applied among recreational exercisers. The two most beneficial effects of resistance training are increased performance and reduced risk of injuries (Lauersen, Bertelsen & Andersen 2014). Resistance training has also showed several positive health effects such as reduced risk for cardiovascular diseases, diabetes, positive effect on bone density and blood lipid profile (Fleck 2011). The most common purpose of resistance training is to stimulate muscle hypertrophy. Muscle hypertrophy is best described as a training stimulated increase of muscle mass. The underlying mechanism is believed to be an accumulation of contractile proteins which will result in muscle growth (Kenny, Wilmore & Costill 2011, p. 230; DeFreitas et al. 2011; The American College of Sports Medicine 2009).

Implementing resistance training into the training plan can improve athletic performance by improving running economy and increased speed at lactic threshold (Paavolainen et al. 1985), increasing peak power output (Rønnestad, Hansen & Raastad 2010), improvement in rate of force development (Aagaard et al. 1985) etc. Regardless of training level, optimizing your training plan is of interest for everyone. Elite athletes that are training 500 to 1100 hours a year have a great winning in optimizing their resistance training since they have to carefully plan what to spend their time on when training (Tønnessen et al. 2014). The recreational exerciser wants to spend as little time as possible in the gym, while still getting great results. Optimizing resistance training is therefore in interest for almost everyone.

Human skeletal muscle is made out of several muscle bundles containing muscle fibres which works together and allows movement. The muscle bundles consist of different types of muscle fibres which are connected to a parent motor neuron and together they form a motor unit. The recruitment of motor units follows a given pattern, called size principle. The motor units are always recruited in a precise order from the smallest (slow twitch) to the largest (fast twitch) units depending on the needed force output (Henneman 1957; Henneman, Somjen & Carpenter 1965). The different types of muscle fibres can be divided into type I and type II. Type I muscle fibres (or slow-twitch muscle fibres) have a high oxidative capacity. Type II muscle fibres (or fast-twitch muscle fibres) have a low oxidative capacity but can generate a lot of force in a short period of time. Type II muscle fibres can also be divided into type IIa and type IIx with similar attributes. Type II is probably the most important muscle fibre when it comes to resistance training and hypertrophy capacity (Kenney, Wilmore & Costill 2011, p. 41; McCall et al. 1996). Type I muscle fibre will also be stimulated for hypertrophy but not to the same extent as type II. Training induced hypertrophy is generally a local effect which means that only the training stimulated muscle fibre will respond to the training. To receive as prominent increases in muscle mass as possible all of the muscle fibres in the muscle needs to be stimulated.

The general recommendations for resistance exercising with the purpose of training induced hypertrophy are 8-12 repetitions, 70-85% of 1RM and 1-3 sets (The American College of Sports Medicine 2009). The intensity in dynamic resistance training is often quantified as a function of the maximum weight that can be lifted only once (one repetition maximum, 1 RM) (Wernbom, Augustsson & Thomeé 2007). According to Morton, McGlory and Phillips (2015) the most important factors for muscle hypertrophy are exercise volume (defined as load x sets x repetitions) and training frequency. It also seems important to execute to contractile failure and include both the concentric and eccentric phase for stimulation of muscle hypertrophy (Goto, Kizuka & Takamatsu 2005; McCall et al. 1996). Wernbom, Augustsson and Thomeé (2007) examined 44 dynamic external resistance studies with protocol designs of two-three resistance sessions a week. The result was a mean increase in quadriceps cross-sectional area (CSA) of 0,11 % per day for both two and three sessions per week, with a range of 0,03-0,26%. Even though research results not clearly indicate a protocol design of three sessions being superior to a two session protocol in terms of increase in CSA, it might be more efficient to induce neuromuscular adaptations and strength gains.

With size principle in mind, heavy resistance training and eccentric training have been shown leading to great increases in muscle growth and strength gains mainly due to greater recruitment of type II fibres (The American College of Sports Medicine 2009). Eccentric resistance training refers to when a muscle tries to contract during lengthening (Herzog 2014). Heavy eccentric resistance training is also more effective than concentric exercise to increase muscle girth (Roig et al. 2008). Heavy resistance training is performed with an intensity of 80-100 % of 1RM, 3-4 sets with 1-6 repetitions (The American College of Sports Medicine 2009).

If an athlete is unable to perform heavy resistance training due to injury, maintaining or rebuilding muscle mass is key for a rapider rehabilitation, since muscle atrophy starts rapidly after injury or inactivity (Wall et al. 2014). A solution to the problem might be a fairly new type of low intensity resistance training called blood flow restricted resistance exercise (BFRE). BFRE is resistance training performed with a low intensity of 15-30 % of 1RM with a total of 30-60 repetitions. One study has shown equivalent increases in muscle CSA of BFRE as of traditional resistance exercise (Wernbom, Augustsson & Raastad 2008). Results that contradicts the recommendation of a higher weight intensity than 70 % of 1RM to induce muscle hypertrophy (The American College of Sports Medicine 2009). BFRE is performed by placing a tourniquet cuff around the proximal portion of either the upper or lower extremity. The purpose of the tourniquet is to restrict the venous blood flow (Pearson & Hussain 2015). As described earlier, recruiting of motor units follows a size principle. It is believed that a high load is necessary to recruit all of the muscle fibres in the trained muscle. However, with BFRE it seems that the restricted venous blood flow decreases the recruiting threshold by fatiguing the muscle more than regular resistance training (Wernbom, Augustsson & Raastad 2008). To summarize, the type 1 fibres will be totally fatigued which results in earlier recruitment of type 2 muscle fibres. This is believed to be one of the reasons of the great results in hypertrophy. Another perk of BFRE is that the muscle damage that occur after heavy resistance training, and especially eccentric training, doesn’t occur following BFRE-training (Loenneke, Thiebaud & Abe 2014). This allows a higher frequency of BFRE in comparison with heavy resistance training. Though, it is still uncertain how much BFRE an athlete can tolerate regarding frequency and training load. Nielsen et al. (2012) have shown that a very high training load (23 sessions within in 19 days) can be tolerated but new unpublished studies (Baekken et al. 2015) indicate that this might be too much for some individuals. The best way to perform high load BFRE-training might therefore be in a periodized manner with 1-2 weeks of BFRE-training separated by 2-4 weeks of rest from BFRE or performing traditional resistance training.

No one has to the best of our knowledge combined high intensity resistance training with BFRE-training when training the lower body. We have only found one study that have combined the two types in an upper body protocol. Yasuda et al. (2011) studied the differences between a high intensity resistance protocol, a low intensity blood-flow restriction protocol and a combined protocol and found out that the combined protocol generated the biggest increase in muscle CSA of the m.triceps brachii. Since no one have combined heavy resistance training with BFRE-training in a lower body protocol, research of the field is clearly needed.

Athletes and trainers use the tool of periodization to optimize their resistance training. Periodization is a method to plan the athlete's training to induce physiological adaptions while managing muscle fatigue (Bompa & Haff 2009, p. 125 f.). There are two basic types of periodization in resistance training called traditional and undulating periodization. Traditional periodization, also entitled step-loading or linear periodization, uses a progression of the training load. The periodization usually stretches over 10-12 weeks with high volume and low intensity in the beginning, with a decreasing training volume but an increasing intensity over time. The second periodization is called undulating, also entitled nonlinear or untraditional periodization, which varies the training load and intensity between every workout (Kok, Hamer & Bishop 2009). It can also be termed mixed-methods resistance training (Newton et al. 2002). In a study by Bartolomei et al. (2015) a weekly-undulating periodization (WUP) showed superior results in thigh-CSA after 10 weeks of training in comparison with a linear block periodization, with an increase of 5,8 % for WUP and 1,6 % for linear block.

Taken together, the literature shows that the following training strategies are efficient to induce muscle hypertrophy:

- 8-12 repetitions, 70-85% of 1RM and 1-3 sets (traditional resistance training)
- 5-7 repetitions, 80-90% of 1RM and 1-3 sets (heavy resistance training)
- 20-30 repetitions, 20-30% of 1RM 2-4 sets (BFRT, 80-100% mmHg)
- 2-3 training sessions/week
- Undulating periodization

Even though many different resistance training protocols have been tested and evaluated no one has combined the above strategies in an attempt to maximize hypertrophy. On top of this, few studies have directly compared muscle hypertrophy in men and women after a period of resistance training. Cureton et al. (1988) tried to examine muscle hypertrophy between men and women and their study indicated that there are most likely no differences between the two groups. As there is little known about muscle hypertrophy between genders, this study will hopefully contribute with more knowledge of eventual differences between men and women, together with the results of our unique resistance training protocol.

1.1 Aim and research questions

The purpose of the present study is to combine efficient strategies from existing literature and research with the attempt to construct the most optimal resistance exercise protocol for muscle hypertrophy. Our hypothesis is that an undulating periodization with mixed-methods of traditional resistance training, eccentric resistance training and BFRE, will produce greater increases of the quadriceps cross sectional area in comparison with other protocols.

- Will our combination of classic resistance training and blood flow restricted resistance exercise (BFRE) training increase quadriceps muscle growth more than other protocols?
- Will there be any differences in muscle growth between men and women?

2 Method

This study is an appendix of a study performed at The Swedish School of Sport and Health Science in Stockholm, working title of the mother study is the Muscle Memory Study (MM-study). Due to the purpose of the MM-study, our training intervention had to be performed with only one leg. The reason why they only trained one leg is that the other leg works as a control leg in the MM-study. All subjects ingested a protein supplement after every training session, also due to the purpose of the MM-study.

2.1 Subjects

A total of 20 healthy subjects (10 men and 10 women) were recruited in the study. Sixteen subjects (n=16) completed the training intervention. One subject quit prematurely due to reasons not related of this study and three subjects were excluded from the results of this study since they did not complete enough training sessions due to sickness or travelling abroad. As the training period consisted of numerous training sessions (34) and to prevent drop outs the selection of subjects were consecutively. Subjects were recruited via advertisements and got accepted to the intervention after an interview. The inclusion criteria's where set as followed; never been performing resistance training and/or endurance training of the lower body regularly and never participated in any sport or activity that stress the lower body. All subjects were informed about the purpose of the study and signed a written informed of consent prior to the pre-tests. All training was performed with one leg that was randomly selected. The subjects' physical characteristics are presented in table 1.

Table 1. Overview of subjects' physical characteristics. Values are presented as mean ± standard deviation.

Groups	Age (y)	Height (cm)	Weight (kg)	Lean body weight (kg)
All (n=20)	24,7 ± 2,9	174,2 ± 8,2	73,2 ± 19,0	58,8 ± 13,8
Men (n=10)	25,1 ± 3,3	182,2 ± 5,5	85,3 ± 17,9	70,4 ± 9,3
Women (n=10)	23,8 ± 2,0	168 ± 3,1	61,0 ± 10,2	47,2 ± 5,1

2.2 Protocol overview

When accepted to the study all subjects had their m. vastus lateralis (VL) muscle thickness measured by an ultrasound screening. Prior to the one repetition maximum test (1RM), all subjects underwent two familiarization sessions. The 1RM-test was performed both to determine their individual training load in the leg press and leg extension, but also to test their maximal strength before the training intervention. Subjects then underwent 8 weeks of weekly undulating resistance training (week 1-3, 5-7 and 9-10) plus two weeks of BFRE-training (week 4 and 8). After the 10-week training intervention subjects had their VL muscle thickness reexamined through another ultrasound screening and 1RM-test were assessed once again to compare their strength pre and post the training intervention (see table 2). Subjects were instructed not to increase or decrease their weekly training routines or make any changes in their normal dietary habits during the training period.

Table 2. Timeline for the training intervention.

	Timeline	
Week	**Performed**	**% 1RM**
1	Ultrasound/Familiarization	-
2	1RM Assessment	100%
3	Resistance training	70-85 %
4	Resistance training	70-85 %
5	Resistance training	70-85 %
6	BRFE	15-30 %
7	Resistance training	70-85 %
8	Resistance training	70-85 %
9	Resistance training	70-85 %
10	BRFE	15-30 %
11	Resistance training	70-85 %
12	Resistance training	70-85 %
13	Ultrasound/1RM Assessment	100%

2.2.1 Familiarization

To minimize the effect of learning, all subjects performed two familiarization sessions prior to the pre-tests and the start of the training period. The familiarizations sessions took place between 1-11 days prior to the first pre-test and there were 24 to 48 hours between the two sessions. During the familiarization sessions the subjects performed three sets, first in the leg extension and then the leg press. Both legs were trained unilaterally. The subjects were instructed to not execute until failure. For standardization, prior to the first set all subjects had their 90° knee joint angle (see figure 1) measured in the leg press and a marking (see figure 2) was placed onto the leg press machine to show subjects when to stop the eccentric phase and start pressing the sled. In the leg extension, subjects started from 90° in the knee joint and performed to a range within 0-20° ending the concentric phase (0° measuring the leg fully extended). A goniometer was used for both measurements, measuring from the lateral malleolus through the lateral epicondyle to the trochanter major of femur.

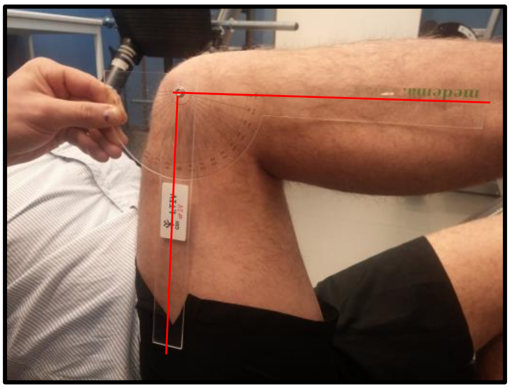

Figure 1. Use of Goniometer for the assessment of 90° angle in knee joint.

Figure 2. The arrow indicates individual marking in the leg press.

2.2.2 Ultrasound screening

Muscle thickness of the VL muscle was measured pre and post of the 10-week training intervention. An ultrasound screening was performed by using Siemens Acuson S1000 (Germany) with a Multi-D matrix 14L5 (5-14 MHz) 4,5cm probe. To ensure good contact without depressing the surface of the VL muscle, the probe was coated with a water-soluble transmission gel. The pre measurements were done before the familiarization training started and the post measurements at least 3 days after their last training session. The examined area of VL was determined by the distance of 25, 50 and 75% between the superior edge of patella and the trochanter major (MP25, MP50 and MP75) (Alegre et al. 2014). Muscle thickness was determined as the distance between subcutaneous adipose tissue interface and intermuscular interface at mid belly. Three measurements were obtained from each point of the VL muscle. During the screening, subjects were supine and instructed to relax in the thigh muscle. To ensure the reliability of the measurement all reference points of the pretest were registered in a coordination system.

2.2.3 Body composition

All subjects had their body composition measured before and after the training intervention. Measurements were done before their 1RM test to avoid the risk of muscle edema. Skinfold measurements were assessed with a Harpenden skinfold caliper (England) and were performed by the same person at both pre- and posttests. Each skinfold measurement was measured in triplet and all points were taken from the dexter part of the subject. The seven measurement points were; triceps, subscapular, chest, midaxillary, suprailiac, abdominal and thigh. A Jackson/Pollock 7 caliper method was used to determine body composition. Bodyweight measurement were performed with a calibrated scale. Subjects were allowed to wear training clothes but not to wear shoes. Bodyweight was rounded off to the closest 0.1 kg. Body height was measured using a calibrated tape and was rounded off to the closest 0,1 cm.

2.2.3 Assessment of one repetition maximum in leg press and leg extension

All subjects performed one repetition maximum (1RM) tests for both their legs before and after the training period. 1RM tests were performed in a Cybex leg press and in a Cybex Eagle leg extension machine (USA). All subjects performed a standardized five-minute warm-up on a Monark Ergomedic 828 E (Sweden) at 60 RPM with 1 kp. Prior to the 1RM test, each subject's predicted 1RM was calculated with the help of an Android application, Rep Max Calculator 2.1.0 (USA). The application calculated a mean value of seven different RM-algorithms (Brzycki, Epley, Lander, Lombardi, Mayhew et al., O'Conner et al. & Wathen) out of the subject's performed weight in the last set of the second familiarization session. Test procedure were then as followed, 10 repetitions at 40-60% of their predicted 1RM with a two-minute rest, five repetitions at 60-80% of their predicted 1RM with a two-minute rest, three repetitions at 90 % of their predicted 1RM with a five-minute rest (Tanner & Gore 2013, p. 213 f.). Subjects then performed single repetition attempts at their predicted 1RM. If the subject was able to complete a dynamic repetition, the weight was increased by 2,5-10% until failure with a three-minute rest between attempts. A successful repetition in the leg press required the subject to perform a knee flexion to or past 90 degrees and extend back to full extension in the knee joint. After performing a 1RM in the leg press subjects rested for three minutes and continued with leg extension. Leg extension implemented the same test protocol procedure except for the first 10 repetition warm-up. A successful repetition in the leg extension required a dynamic knee extension from a starting 90-degree knee flexion to a knee extension within the range of 0-20° in the knee joint. The supervisor (SV) was placed laterally from the subject both in the leg press and leg extension during the 1RM. If the subject didn't perform a standardized dynamic repetition without the help of the SV, the SV registered it as an unsuccessful attempt.

2.2.4 Training intervention

The subjects participated in a 10 week supervised training program consisting of 34 training sessions. Training was performed three days a week (mon/wed/fri) except for week 4 and week 8 where subjects had to exercise once every day from Monday to Friday. Week 1-3, 5-7 and 9-10 followed a weekly undulating periodization (WUP). Week 4 and week 8 consisted of BFRE-training. Subjects only trained one leg during the entire training period (see appendix 2 for a more detailed training overview). Following a short warm-up of one set of 10 repetitions in the leg press with an intensity of 20 kg and one set of 10 repetitions with 50 % of the working set load, subjects performed three sets of unilateral leg press and rested for 2-3 minutes before performing three sets of unilateral leg extension during week 1-3, 5-7. To achieve a tapering effect for our subjects, the amount of sets was decreased during week 9 and week 10. Only one set was performed on Wednesday during week 9 and 10. During the last week (10) subjects only performed two sets on Monday and Friday (see table 3).

Table 3. Training volume and intensity during week 1-3, 5-7 and 9-10. The sun (¤) indicate that during week 10 only 2 sets where performed, M=Monday.

	Week 1-3, 5-7			Week 9-10		
	Monday	**Wednesday**	**Friday**	**Monday**	**Wednesday**	**Friday**
Intensity	70-75 %	90 % of M	80-85 %	70-75 %	90 % of M	80-85 %
Sets	3	3	3	2-3 *	1	2-3 ¤
Reps	10-12	10-12	5-7	10-12	10-12	5-7

The WUP consisted of a high repetition session on Monday with three sets of 10-12 repetitions with 70-75 % of 1RM. Subjects were encouraged to execute to failure in the last two sets. Rest between sets where 1-2 minutes. The Wednesday session, with the purpose to increase training frequency, consisted of three sets of 10-12 repetitions with 90 % of the training intensity at the Monday session, not executing to failure. Rest between sets where 1-2 minutes. On Friday, subjects performed a higher intensity session with three sets of 5-7 repetitions with 80-85 % of 1RM with focus on executing slow during the eccentric phase and executing to failure in the last two sets. Rest between sets where 2-3 minutes.

During week 4 and week 8 subjects exercised every day. Subjects exercised only in the leg extension on Monday, Wednesday and Friday. Leg press were only performed on Tuesday and Thursday. Before each training session a Delfi Medical low pressure tourniquet cuff (30-77cm, USA) were applied to the proximal portion of the thigh. The cuff was connected to a Zimmer A.T.S. 2000 tourniquet system (USA) that automatically applied and regulated the pressure to 100 mmHg. Subjects then performed four sets of unilaterally leg press or leg extension at a set pace of 60 BPM in the leg extension and 50 BPM in the leg press. Pace was given by a metronome and was enhanced by the SV holding it. The intensity was set at 20 % of 1RM in leg extension and 30 % of 1RM in the leg press. Protocol was as following: first set consisted of 30 repetitions with a 30 second rest, second set consisted of 10 repetitions with a 30 sec rest, in the third and fourth set subjects were encouraged to execute to concentric failure with a 30 sec rest between set three and four (see table 4). Failure was standardized as when the subject wasn't able to keep up with the pace or couldn't extend fully after two warnings. If subjects had problems initiating the concentric phase in set 3 and set 4, due to massive blood accumulation in the thigh, the SV helped with initiating the first or second repetition. Tourniquet cuff pressure was kept during the entire training session and was released immediately upon completion of set four. If subjects were unable to complete the set amount of reps in set number one and two or not more than five repetitions in the third set, training intensity was decreased by 5 % to 15 % (leg extension) respectively 25 % of 1RM (leg press) to the next training session. If a decrease of weight intensity wasn’t enough, tourniquet pressure was decreased to 90 mmHg. Acute changes to tourniquet pressure was applied in set three and four if the subject couldn’t complete more than five repetitions in set two. If an acute decrease was needed, tourniquet pressure was decreased to 90 mmHg.

Table 4. Training volume, intensity, pressure and exercise for week 4 and 8.

	Week 4 and 8	
	Mon-Wed-Fri	**Tues-Thur**
Exercise	Leg extension	Leg press
Pressure	100 mmHg	100 mmHg
Intensity	15-20 %	25-30 %
Reps Set 1	30	30
Reps Set 2	10	10
Reps Set 3	Failure	Failure
Reps Set 4	Failure	Failure

To not be excluded from the training intervention, subjects weren’t allowed to miss more than 20% of the total amount of training sessions during the whole intervention or more than three training sessions in a row. Due to the long training period no sessions were added after the 10-week period of training.

2.3 Nutrition

The only standardization in terms of nutrition was that protein supplements were ingested after each training session during the 10-week intervention. This standardization was implemented to attempt that the subjects had a sufficient protein intake (Schoenfeld, Aragon & Krieger 2013). Each portion contained 23,4 gram of whey protein (FitnessGuru One Whey) and was mixed with a free amount of water. 3 out 20 subjects were given an organic protein (Fitness Guru Hemp Protein) and each portion contained 21 gram vegetable protein. None of the subjects were allowed to use any performance enhancing supplements.

2.4 Validity, reliability and ethics

To establish this study reliability and validity pilot tests were performed on the 1RM test and BFRE training prior to the training intervention. Ultrasound screening is a valid method for measuring skeletal muscle size (Pretorius & Keating 2008). Noorkoiv, Nosaka and Blazevich. (2010) tested the validity of measuring CSA via ultrasonography against computed tomography (CT), which is one of two golden standard methods. Validity was tested by intra class correlation between the two methods. Their results showed that a mid-thigh measurement had the highest ICC score and lowest standard error of 0,6%. Results of MP50 will therefore be the most interesting as of this study. According to Tanner and Gore (2013, p.4) typical error for Skinfold Caliper measurement is <5%.

All subjects were informed with the purpose and risks of participating in the study and all signed a written informed of consent (Vetenskapsrådet u.å.) (see appendix 3). Though they only exercised one leg for 10 weeks, all subjects are going to exercise both legs during the second training period of the MM-study. We also provided everyone with an upper body exercise program and access to the school's gym facilities twice a week. All data where treated with care and all subjects were anonymized during data handling and analysis. The present study is an appendix of a study performed at The Swedish School of Sport and Health Science, which is approved by the regional board of ethics, DNR 2015/211-31/4.

2.5 Statistical analysis

All values are reported as means ± SD or percent change or both from pre and post the training intervention. Means and SD were calculated in Microsoft Excel 2016 (Microsoft Corporation, Redmond, Washington, USA). Statistical analyses were performed with IBM SPSS Statistics Version 22 (IBM, New York, USA). Pre and post results were analyzed with a paired dependent T-test. Differences between groups were analyzed with an independent T-test. The level of statistical significance was set at $p \leq 0,05$.

3 Results

3.1 Subjects

Sixteen subjects (9 women and 7 men) completed 32 ± 1,4 of 34 possible training sessions. No differences were seen between pre and post measurements in both weight and lean body weight (see table 5).

Table 5. Subjects physical characteristics before and after the 10-week training intervention. Values are presented as mean ± standard deviation.

	Weight (kg)		Lean body weight (kg)	
Groups	**Pre**	**Post**	**Pre**	**Post**
All (n=16)	70,6 ± 17,2	70,6 ± 16,5	56,3 ± 11,9	55,5 ± 10,5
Men (n=7)	81,6 ± 18,1	81,7 ± 17,3	67,3 ± 8,5	65,7 ± 6,6
Women (n=9)	62 ± 10,2	61,9 ± 9,1	47,7 ± 5,2	47,6 ± 4,7

Throughout the training intervention all subjects performed two weeks of blood flow restricted resistance exercise (BFRE) and the amount of repetitions performed in each set are presented in table 6.

Table 6. Mean amount of repetitions performed during the two BFRE weeks in each set. Values are presented as mean ± standard deviation.

Exercise	Set 1	Set 2	Set 3	Set 4
Leg extension	29,7 ± 0,6	9,4 ± 1,1	8,9 ± 3,0	4,4 ± 1,2
Leg press	29,7 ± 0,8	9,1 ± 1,7	7,9 ± 3,6	4,5 ± 2,5

3.2 Muscle thickness

10 weeks of unilateral resistance training increased muscle thickness at MP50 and MP75 by 15,1 % ± 7,6 ($p \leq 0,01$) resp. 7,4 % ± 8,7 ($p \leq 0,01$). MP25 was not affected by the training intervention (see figure 3).

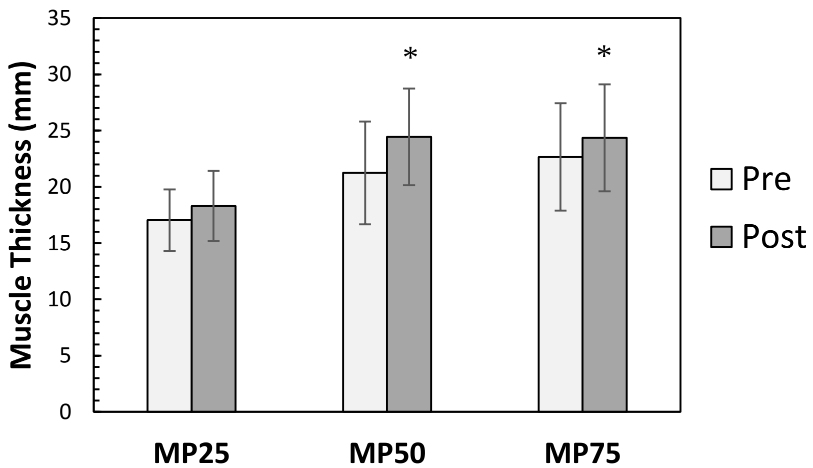

Figure 3. Muscle thickness in the vastus lateralis (VL) muscle of the trained leg at MP25, MP50 and MP75 before and after the training intervention. Results are means ± standard deviation. Asterix (*) indicates a significant difference.

A minor increase in muscle thickness was also observed at MP50 in the untrained leg by 4,4 % ± 4,9 (p ≤ 0,01) (see figure 4).

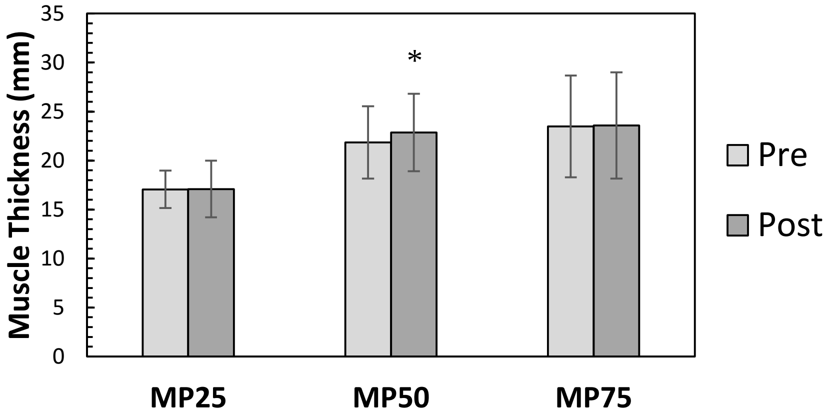

Figure 4. Muscle thickness in the vastus lateralis (VL) muscle of the untrained leg at MP25, MP50 and MP75 before and after the training intervention in the untrained leg. Results are means ± standard deviation. Asterix (*) indicates a significant difference.

3.3 Maximal strength

Maximal strength in the trained leg increased for the entire group in the leg press by 59,1 % ± 27,4 (p ≤ 0,01) and in the leg extension by 19,8 % ± 13,1 (p ≤ 0,01) (see figure 5).

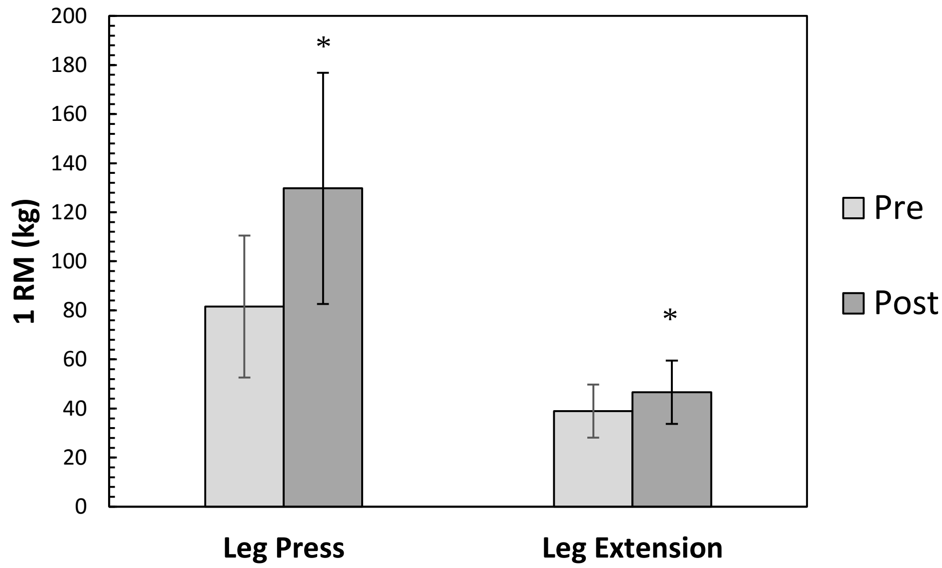

Figure 5. 1RM in leg press and leg extension of the trained leg before and after the training intervention. Results are means ± SD. Asterix (*) indicates a significant difference.

Maximal strength also increased for the whole group in the untrained leg by 18,9 % ± 18,9 in the leg press ($p \leq 0,01$) and 6,7 % ± 8,3 in the leg extension ($p \leq 0,05$) (see figure 6).

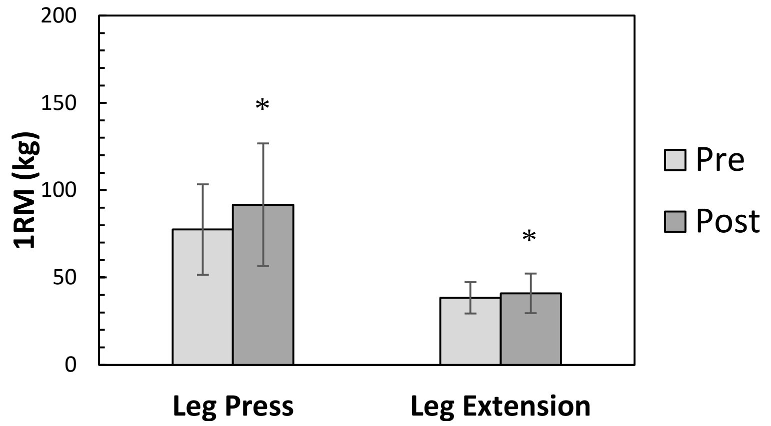

Figure 6. 1RM in leg press and leg extension of the untrained leg before and after the training intervention in the untrained leg. Results are means ± standard deviation. Asterix (*) indicates a significant difference.

3.4 Gender differences

MP25 increased in women by 6,7 % ± 6,7 ($p \leq 0,05$) but not in men. At MP50 and MP75 muscle thickness increased in both groups, men by 15,4 % ± 9,3 ($p \leq 0,01$) resp. 6,9 % ± 2,0 ($p \leq 0,01$) and women by 14,8 % ± 6,0 ($p \leq 0.01$) resp. 7,9 % ± 11,3 ($p \leq 0,05$). No difference was seen in the increase in VL muscle thickness between men and women (see figure 7).

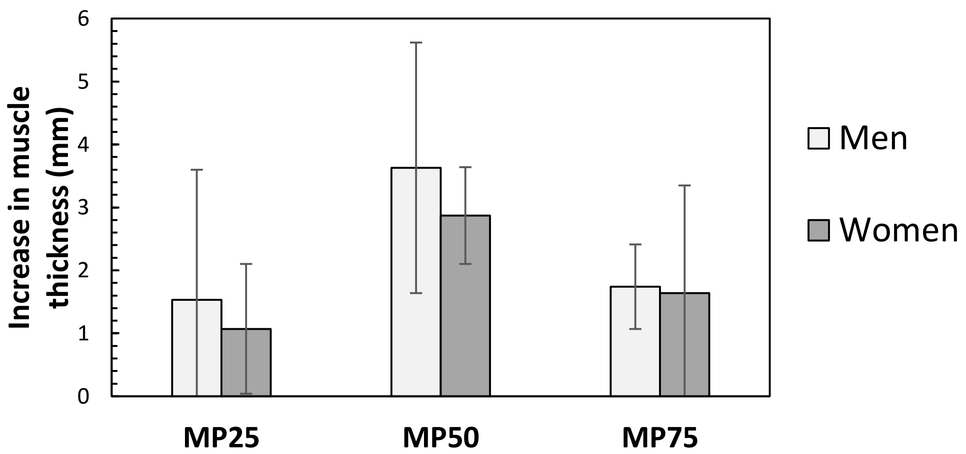

Figure 7. Difference between men and women in muscle thickness increase in the vastus lateralis muscle of the trained leg after the training intervention. Results are means ± standard deviation.

An increase was also seen in women in the untrained leg at MP50 with 3,5 % ± 4,4 ($p \leq 0,05$, data not shown)

Maximal strength increased in leg press for men ($p \leq 0,01$) but in both exercises for women ($p \leq 0,01$). Men had an increase of 58,1 % ± 18,0 % and women with 60,3 % ± 32,8 in the leg press. In the leg extension women increased their maximal strength by 23,3 % ± 7,4. Men had an almost significant increase in leg extension by 17,0 % ± 14,4 (p = 0,051). No difference was seen in the increase in maximal strength between men and women (see figure 8).

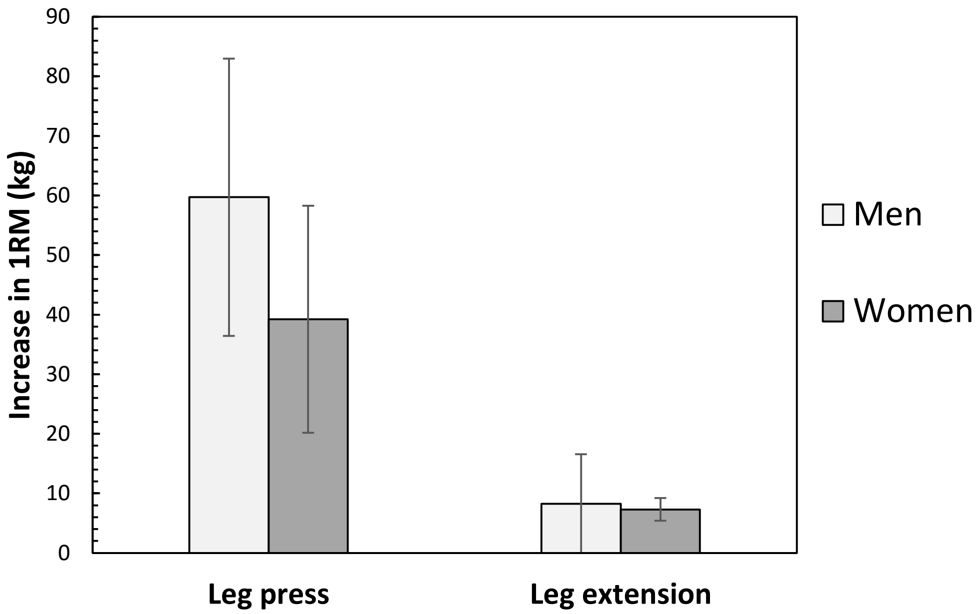

Figure 8. Difference between men and women in the 1RM increase of the trained leg after the training intervention. Results are means ± standard deviation.

Both men and women increased their maximal strength in leg press in the untrained leg ($p \leq 0,01$) but only men increased their strength in the leg extension ($p \leq 0,05$). In the leg press men increased their maximal strength by 26,5 % ± 20,3 and women by 9,5 % ± 13,0. In the leg extension men increased by 9,8 % ± 9,4 (data not shown).

4 Discussion

The present study is the first to examine the effect of combining traditional high volume resistance training, high intensity eccentric resistance training and BFRE-training in the lower extremity. The major finding of this study was that our unique resistance training protocol resulted in a approx. 15 % increase in muscle thickness in the m. vastus lateralis muscle. No significant difference in muscle growth was seen between men and women after the training intervention.

There seems to be a strong correlation between muscle thickness and CSA in the lower extremity. Hulmi et al. (2009) measured both muscle thickness and CSA of VL after 21 weeks of resistance training. Results are presented in two separate studies with almost the same groups. One group that used protein supplements increased their VL muscle CSA by 14,8 % and muscle thickness by 12,2 % which gives a 1:1,21 ratio. The placebo group increased their VL muscle CSA by 11,2 % and muscle thickness by 10,1 % which gives a 1:1,11 ratio. The ratio between VL muscle CSA and VL muscle thickness can therefore be estimated to 1:1,15. Applying this ratio to our results gives a mean increase in VL muscle CSA by 17,3 % or 0,25 % per day. A result severely superior to the mean increase of 0,11 % per day presented in the review of training factors affecting quadriceps muscle CSA (Wernbom, Augustsson & Thomeé 2007). It's also in the top of the range (0,03-0,26 %) of the 44 dynamic external resistance studies included in the review, all with a training frequency similar as this study. Our combined resistance training protocol seems to have resulted in superior increases in quadriceps muscle hypertrophy in comparison to earlier studies.

Kraemer et al. (1998) discuss the possibility of bilateral or whole body programs leading to a greater augmentation in testosterone concentration than unilateral resistance training. Due to greater musculature recruitment it's believed to produce more testosterone which ultimately leads to greater increases in muscle hypertrophy. This study was an appendix of another study which required one leg to be untrained. This forced us into having our subjects performing unilateral resistance training. If we would've had the opportunity we probably had chosen a bilateral training program instead of a unilateral training program, primarily because of the ethical aspect of letting subjects exercise both legs instead of just one. However, there doesn't seem to be that big of a difference between unilateral- and bilateral resistance training in muscle hypertrophy according to Häkkinen et al. (1996). In their study, two groups of middle-aged men and women performed heavy resistance training on knee extension and flexion muscles, where one group performed bilateral training and the other unilateral training. They found no significant differences in muscle hypertrophy between the groups after the training intervention. Despite the slight possibility of bilateral training producing more testosterone, our unilateral resistance training results stand tall in comparison with earlier strength training studies. In comparison with other strength training studies, with previously untrained subjects exclusively performing unilateral resistance training as this present study, our increase in CSA are superior (Ivey et al. 2000; Häkkinen et al. 1996). One exception is Beyer et al. (2015), which after only 4-weeks of unilateral resistance training got a questionable increase of 15,7 % in CSA of the quadriceps muscle (0,56 % per day). Their subjects performed 3 sets of 8 unilateral repetitions at 80 % RM in the lower limb and bilateral resistance training in the upper body during a 4-week training intervention. With no significant increase in testosterone concentration and the quite standard training protocol, one explanation might be delayed muscle edema. Damas et al. (2016) contend that early increases in VL CSA (in the third week or after four bouts of resistance training) are largely due to edema-induced muscle swelling. It is possible that only one additional week (or three additional training sessions) as of Beyer et al. (2015) is not enough to exclude muscle edema affecting the measurement. Damas et al. (2016) argues that increases in CSA after 9-12~ resistance training bouts can be overestimated and should be taken with ease. Another interesting finding was that they found no significant muscle swelling after 10 weeks of resistance training. Similar to this study they measured muscle growth through ultrasound screening 72 hours or more after the last training session. A result that excludes the possibility of our increases being affected by edema-induced muscle swelling.

Our training intervention resulted in no significant difference between men and women in muscle growth. These results are in line with Cureton et al. (1998) which concluded that there is no difference between untrained men and women in muscle growth after their resistance training intervention. Also, no significant difference could be seen between men and women in maximal strength of both exercises after our training intervention. Though this training intervention was designed to optimize muscle hypertrophy, our results are in line with other strength studies regarding the increase in maximal strength (Häkkinen et al. 1996). This resistance training program can therefore successfully be applied by both genders to receive both great increases in muscle growth and maximal strength. Further research is needed to investigate if there is a difference in the response of this training protocol between men and women at a higher training level.

The most unique thing about this study’s training protocol is the addition of BFRE-training. Performing BFRE can be physically and mentally tough for the athlete due to severe pain in the trained limb due to massive blood accumulation. We prepared our subjects mentally before the BFRE-weeks by explaining the procedure and sharing our own expressions from the pilot tests that were done prior to the start of this study. One of our fears with having untrained subjects was that they weren’t going to manage the pain in the trained limb since they’ve never had trained regularly before. Though a majority performed exceptionally well from the very beginning, some didn’t. Extra focus was given these subjects and they were encouraged to carry on despite the discomfort. After only few sessions they learned to handle the pain and from that on all of the subjects gave everything they had during the rest of the intervention. We recommend BFRE to be performed together with a trainer and other athletes that can encourage and cheer at the athlete, for superior results. Even though it might sound like there's a risk encouraging untrained subjects to continue with severe pain in the limb, there's no evidence that BFRE damages the muscle. According to Loenneke, Thiebaud and Abe (2014) BFRE does not result in any muscle damage when measuring blood biomarkers for muscle damage and muscle soreness ratings in comparison with a low-load control.

BFRE-training therefore gives strength coaches another tool in their arsenal when programming their athletes' training. Optimizing the strength training program for maximal muscle growth, without severe muscle soreness or damage to tissues will give athlete's more time to focus on other capacities as well.

4.1 Limitations

To increase the validity of the ultrasound measurement Berg, Tedner and Tesch (1993) suggest that the subject should be rested in a horizontal position for 15-20 minutes before performing the ultrasound screening. The reason is to allow the fluids to shift to stabilize. Due to a limited amount of time, our subjects only sat in an upright position for 5-20 minutes prior to the ultrasound measurement. This might've impacted the measurement of this study. The best would've been using a computed tomography, as it is the golden standard method.

One of the inclusion criterias in the meta-analysis of Wernbom, Augustsson and Thomeé (2007) was that no protein supplement or other performance enhancing supplements were consumed by the subjects. However, all of our subjects were given a protein supplement after training. This must be taken into consideration when comparing our results with the results from the meta-analysis. It is however questionable that the supplemented protein would have had any major impact on the observed muscle growth because studies normally show minor or no effect of protein supplementation on hypertrophy (Hulmi, Lockwood & Stout 2010; Hulmi et al. 2015).

4.2 Conclusion

The major finding was that the unique resistance training protocol applied in the present study induced an unusually large increase in muscle growth compared with similar strength training studies. Both men and woman responded well to the training and no gender differences were observed. The present training protocol, where classic resistance training is combined with BFRE, can therefore be recommended to individuals who want to maximize their hypertrophy.

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Appendix 1

Source and literature search

Purpose and question formulation:

The purpose of the present study is to combine efficient strategies from existing literature and research with the attempt to construct the most optimal resistance exercise protocol for muscle hypertrophy. Our hypothesis is that an undulating periodization with mixed-methods of traditional resistance training, eccentric resistance training and BFRE, will produce greater increases of the quadriceps cross sectional area in comparison with other protocols.

- Will our combined resistance training protocol of high volume, high intensity and blood flow restriction training increase quadriceps muscle growth more than other protocols?
- Will there be any differences in muscle growth between men and women?

Which words have you been using during your literature search?

Wernbom, Kraemer, blood flow restriction training, heavy resistance training untrained, resistance training, strength training, kaatsu, quadriceps, cross sectional area, muscle hypertrophy, hypertrophy, cross sectional area, CSA quadriceps, muscle growth, lower body, periodization resistance training, weekly undulating resistance training, untrained men, untrained women, protein, protein intake,

Where have you search?

PubMed, Sport Discus, Google Scholar,

Which of the literature searches gave relevant results?

PubMed: heavy resistance training untrained, blood-flow restriction training
PubMed: review resistance training hypertrophy

Comments

We've received great help with literature and studies by our supervisor Niklas Psilander and from Mathias Wernbom (Uni of Gothenburg) in the field of strength training and BFRE-training. Many reviews or meta-analyses have given us references to original articles that we've used in this thesis.

Appendix 2

Training Intervention

Week 1:

Monday: 2 set leg press + 2 set leg extension, 10-12 reps (~70-75 % of 1RM) until failure, moderate velocities (1-2 sec for the concentric and eccentric phase), 1-2min rest between set and machine.

Wednesday: Same sets and reps as Monday but 90% of the intensity as Monday

Friday: 2 set leg press + 2 set leg extension, 5-7 reps (~80-85 % of 1RM) until failure, emphasis on the eccentric phase (2-3 sec).

Week 2 and 3:

Monday: 3 set leg press + 3 set leg extension, 10-12 reps (~70-75 % of 1RM) until failure, moderate velocities (1-2 sec for the concentric and eccentric phase), 1-2min rest between set and machine.

Wednesday: Same sets and reps as Monday but 90% of the intensity as Monday

Friday: 3 set leg press + 3 set leg extension, 5-7 reps (~80-85 % of 1RM) until failure, emphasis on the eccentric phase (2-3 sec).

Week 4 (BFRE):

Monday: 4 sets of leg extension at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure

Tuesday: 4 sets of leg press at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure

Wednesday: 4 sets of leg extension at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure

Thursday: 4 sets of leg press at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure

Friday: 4 sets of leg extension at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure

Week 5-7:

Monday: 3 set leg press + 3 set leg extension, 10-12 reps (~70-75 % of 1RM) until failure, moderate velocities (1-2 sec for the concentric and eccentric phase), 1-2min rest between set and machine.

Wednesday: Same sets and reps as Monday but 90% of the intensity as Monday

Friday: 3 set leg press + 3 set leg extension, 5-7 reps (~80-85 % of 1RM) until failure, emphasis on the eccentric phase (2-3 sec).

Week 8 (BFRE):
Monday: 4 sets of leg extension at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure
Tuesday: 4 sets of leg press at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure
Wednesday: 4 sets of leg extension at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure
Thursday: 4 sets of leg press at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure
Friday: 4 sets of leg extension at 15-20% 1RM, 30s rest between sets, set 1: 30 reps, set 2: 15 reps, set 3 and 4 until failure

Week 9:
Monday: 3 set leg press + 3 set leg extension, 10-12 reps (~70-75 % of 1RM) until failure, moderate velocities (1-2 sec for the concentric and eccentric phase), 1-2min rest between set and machine.
Wednesday: 1 set leg press + 1 set leg extension, 90% of the intensity as Monday
Friday: 3 set leg press + 3 set leg extension, 5-7 reps (~80-85 % of 1RM) until failure, emphasis on the eccentric phase (2-3 sec).

Week 10:
Monday: 2 set leg press + 2 set leg extension, 10-12 reps (~70-75 % of 1RM) until failure, moderate velocities (1-2 sec for the concentric and eccentric phase), 1-2min rest between set and machine.
Wednesday: 1 set leg press + 1 set leg extension, 90% of the intensity as Monday
Friday: 2 set leg press + 2 set leg extension, 5-7 reps (~80-85 % of 1RM) until failure, emphasis on the eccentric phase (2-3 sec).

Appendix 3

Informerat samtycke (biobank)

Undertecknad har tagit del av den skriftliga informationen.
Jag accepterar
att delta i forskningsstudien rörande ” Har människan ett muskelminne?” och har förstått att mitt deltagande är helt frivilligt och kan avbrytas när som helst utan någon förklaring.

Jag godkänner
att de vävnadsprov som jag lämnar kommer att förvaras i biobank vid GIH (Gymnastik- och Idrottshögskolan),

att proverna används på det sätt som beskrivits i forskningspersonsinformationen men att jag när som helst kan återkalla mitt samtycke till användning av mina prover och begära att proverna omedelbart förstörs eller avidentifieras,

att proverna används i framtida biomedicinsk forskning som inte är beskriven här och som i förekommande fall kommer att granskas och godkännas av regional etikprövningsnämnd samt att i samband med sådan forskning journalkopior eller information baserad på min journal lämnas ut (stryks om forskningspersonen motsätter sig det).

Datum:………………………………

Underskrift:……………………………………………….

Namnförtydligande:……………………………………….

Personnummer ☐ ☐ ☐ ☐ ☐ ☐ - ☐ ☐ ☐ ☐

Dokumentet är upprättat i två original varav forskningspersonen behåller den ena och det andra arkiveras av ansvarig prövare.