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Comparative Regional Hypertrophic Effects of Two Once-Weekly Resistance Training Programs on Quadriceps Muscle

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Abstract This study aimed to investigate the regional hypertrophic effects of two different once-weekly resistance training programs on the quadriceps muscle. Eighteen untrained men (Age: 21.1±0.5 years, Height: 174.1±5.3 cm, Body weight: 68.8±11.3 kg) with no prior resistance training experience were recruited. Participants were randomly assigned to one of two once-weekly training programs: a Mechanical Tension program (TN) or a Mechanical Tension with Metabolic Stress program (TS), both progressively designed over 6 weeks. Quadriceps muscle cross-sectional areas (QCSA) were measured using magnetic resonance imaging (MRI) at three regions—proximal, middle, and distal—before and after training. The finding demonstrated that QCSA significantly increased in the proximal region (Δ9.97%, ES = Moderate, and Δ8.9%, ES = Moderate), middle region (Δ8.19%, ES = Moderate, and Δ8.42%, ES = Moderate), and distal region (Δ7.73%, ES = Moderate, and Δ7.76%, ES = Moderate) for the TN and TS groups, respectively. Maximum strength also significantly increased in both group (Δ26.83% in TS and Δ19.82% in TN with ES = Large). Additionally, strong to very strong positive correlations were found among the different regions (r = 0.82–0.94, p = 0.000), which may suggest that measuring a single region could be sufficient for those with budgetary constraints. In conclusion, both training programs effectively induced quadriceps hypertrophy, as well as resulting in increased maximum strength, in untrained participants, highlighting the effectiveness of one-weekly training in promoting muscle growth. Additionally, the knee extension exercise demonstrated the ability to induce relatively uniform hypertrophy across all quadriceps regions.

Keywords Quadriceps Muscle, Cross-Sectional Area, Hypertrophy Training

1. Introduction

Strength training was widely recognized for its various benefits, one of which was increasing muscle mass, academically referred to as muscle hypertrophy [1]. This adaptation not only improved physical appearance but also contributed to overall health and well-being through increased muscle mass [2]. Resistance training with machines, in particular, was proved to be very effective in promoting hypertrophy because it provided a high degree of stability, allowing targeted muscles to be trained in isolation [3]. Several studies recently investigated the effects of different machine-based training on muscle hypertrophy and hypertrophy-related outcomes. For instance, the research examined the impact of machine knee extension training on lean quadriceps hypertrophy [4] and Smith-machine chest press on pectoralis activation [5].

Physiologically, the hypertrophic process in skeletal muscle was stimulated by three key factors: mechanical tension, metabolic stress, and muscle damage [6].

Mechanical tension, the primary stimulus for hypertrophy, depended on external loads (>70% of one-repetition maximum, 1RM), which triggered molecular signaling for increased muscle protein synthesis, leading to muscle fiber growth [7,8]. Metabolic stress, resulting from prolonged time under tension and higher repetitions, leads to muscle growth through the accumulation of metabolites, cellular swelling, hypoxia, and hormonal responses [9,10]. Muscle damage, caused by repetitive stretching and shortening during training, played a minor role in early adaptation [11]. Recently, blood flow restriction (BFR) resistance training gained attention for inducing hypertrophy at low intensities (<50% 1RM) [12]. For example, BFR training at 30% 1RM was shown to increase Type-II fiber cross-sectional area after 6 weeks of training [13]. However, theoretically, BFR might still induce suboptimal mechanical tension compared to traditional high-intensity training, despite its impressive size adaptations [14].

In terms of training frequency, the American College of Sports Medicine recommended 2–3 days per week for hypertrophy, particularly for novice and intermediate practitioners [15]. However, not everyone could commit to this frequency, which might discourage those who found it difficult to train multiple times a week from engaging in resistance training. Fortunately, recent review by Iversen and the team suggested that training just once a week could still be effective for inducing muscle hypertrophy [16]. This was supported by a meta-analysis showing no significant impact of training frequency on muscle hypertrophy when training volume was matched by training once a week and that training frequency could also be effective if the volume was enough [17]. However, research on the effectiveness of once-weekly training remains scarce, and more evidence is needed to validate its efficacy.

Given these findings, an ideal training program should have targeted all key mechanisms of hypertrophy—mechanical tension, metabolic stress, and muscle damage—while minimizing training frequency to save time. Therefore, this study aimed to investigate the regional hypertrophic effects of two different once-weekly resistance training programs on quadriceps muscle.

2. Materials and Methods

2.1. Study Design and Ethics

The study aimed to investigate the hypertrophic effects of two different once-weekly resistance training programs on different regions of the quadriceps. This study employed the two-group experimental design, with standardized controls for training variables such as numbers of sets, environmental setting, training equipment, repetition tempo, and rest intervals. Eligibility criteria required participants to have no prior resistance training experience to minimize experience-related biases. Resistance training was supervised by a certified personal trainer. Baseline testing included measurement of quadriceps cross-sectional area (QCSA) at proximal, middle, and distal regions. This study employed written informed consent and conformed to the ethical guidelines of the Declaration of Helsinki as well as ethical approval which was granted by the Burapha University ethics committee (G-HS046/2566(C1).

2.2. Participants

Before implementing the exercise intervention, the sample size was calculated using G*Power 3.1.9.7 software. The priori power analysis included an effect size of 0.75, $\alpha = 0.05$, and power = 0.80, following a previous study that employed a similar two-group experimental design investigating resistance training effects on muscle hypertrophy [18]. The total sample size was 17, and considering a 20% dropout rate, the total number of participants in this study was 20. All participants were healthy young male undergraduates, aged 18 to 22 years, with no current injuries. The inclusion criteria ensured that participants had 1) no functional limitations, 2) no history of substance use affecting muscle metrics, and 3) no prior resistance training experience. General health screenings were conducted by a registered physician, and written informed consent was obtained from all participants. Participants were randomly assigned to either the mechanical tension program (TN, n = 10) or the mechanical tension with metabolic stress program (TS, n = 10) using the research randomizer (www.randomlist.com).

2.3. Resistance Training Programs

In the Mechanical Tension (TN) program, participants completed three sets of knee extension exercises, utilizing a pin-loaded bilateral knee extension machine (Body-Solid, USA) for the first two weeks. These sets were aimed to induce mechanical tension stimulus by using high-intensity set at 70% 1RM. The 1RM for each participant was established one week prior to the study's commencement, following the National Strength and Conditioning Association guidelines [19]. Specifically, participants began with an aerobic warm-up, then specific light knee extension for 8-10 repetitions. After a one-minute rest, weight was incrementally increased, allowing participants to perform 3-5 repetitions. After a four-minute rest period, the load was increased by 10%, with participants attempting a single repetition. This process was repeated, with three-minute rests between attempts, until the maximum weight that could be lifted was recorded as the 1RM. In weeks 3-4, the set volume was increased to 6 sets at 70% 1RM, and in weeks 5-6, it was further increased to 8 sets at the same intensity. Repetitions were performed until concentric failure to ensure maximal muscle fiber recruitment, optimizing hypertrophic outcomes. Each repetition followed a consistent tempo of 2 seconds for both concentric and eccentric phases, controlled via metronome, with 60-second rest periods between sets. Participants were required to maintain a full range of motion for each repetition (Figure 1).

Figure 1. A random participant demonstrating knee extension with full range of motion, starting position and finishing position of eccentric phase (A) and finishing position of concentric phase (B) of exercise

In the Mechanical Tension with Metabolic Stress (TS) program, participants performed two sets at 70% 1RM to induce mechanical tension, followed by one set at 30% 1RM, incorporating practical blood flow restriction to induce metabolic stress stimulus during the first two weeks. The objective of the metabolic-stress set was to enhance the accumulation of metabolites and induce localized hypoxia in the quadriceps [10]. To optimize these metabolic stress conditions, the practical blood flow restriction technique was employed. Elastic wraps (Grizzly Fitness, Canada) were fastened at the proximal region of upper legs, aiming to achieve at least 40% arterial occlusion pressure (AOP). Prior to the study, participants familiarized themselves with their perceived 40% AOP level using adjustable pneumatic cuffs (H+Cuff, USA). In weeks 3-4, the training volume was increased to 3 mechanical-tension sets and 3 metabolic-stress sets, and in weeks 5-6, the volume was further raised to 4 sets for both mechanical tension and metabolic stress. All other training variables, including repetition tempo and rest periods, remained consistent across the groups.

2.4. Regional Hypertrophy Assessments

Regional quadriceps cross-sectional areas were measured using a 1.5-T magnetic resonance imaging (MRI) scanner (Vantage Elan, Canon, USA). This step was conducted by a certified clinical radiologist. The imaging protocol included standard axial and coronal T1-weighted and T2-weighted fat-saturated sequences. Quadriceps cross-sectional area measurements were obtained at three specific locations along the femur length: 30% (proximal), 50% (middle), and 70% (distal) of the femur's total length, measured from the greater trochanter to the lateral epicondyle. An example image was shown in Figure 2.

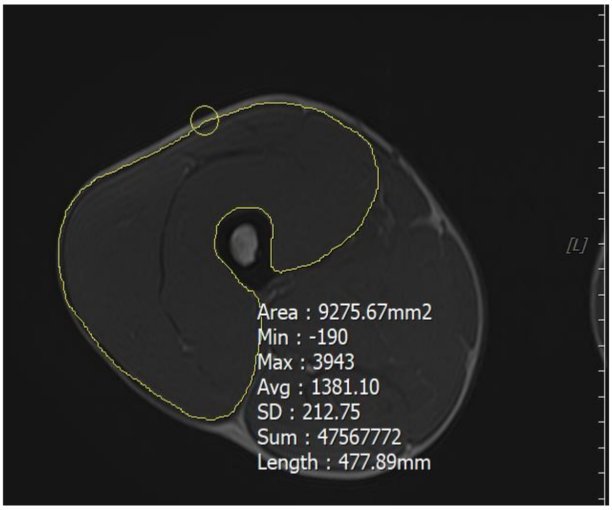


Figure 2. An example image of the quadriceps cross-sectional area from a random participant

2.5. Statistical Analysis

The statistical analysis was calculated by IBM SPSS Statistics version 20. The Shapiro-Wilk test was used to analyze the normal distribution of data. Descriptive statistics: mean and standard deviation, were used to summarize baseline characteristics. Then, baseline variables between groups were initially compared by One-way ANOVA. Levene's test assessed the homogeneity of variances. Changes in QCSA of all regions from baseline to Post-test were calculated, with a 95% Confidence Interval. A two-way repeated measured ANOVA was employed to compare between-group (TN vs. TS) and between-time (Pre vs. Post) effects. Cohen's (d) effect sizes were calculated using the formula: mean change/pooled SD, with interpretations based on conventional criteria of 0.00–0.19 considered as Trivial, 0.20–0.49 as Small, 0.50–0.79 as Moderate, and ≥0.80 as Large. A significance level was set at $\alpha = 0.05$. Moreover, the Pearson's (r) correlation was also calculated to examine the relationships among regions at both pre and post-test.

3. Results

Of the 20 participants initially recruited, two from the TS group withdrew—one due to a lack of interest and the other because of a knee injury. As a result, the final analysis comprised 8 participants in the TS group (age: 21 ± 0.0 years, height: 174.9 ± 5.3 cm, weight: 69.0 ± 11.9 kg) and 10 participants in the TN group (age: 21.3 ± 0.7 years, height: 173.1 ± 5.5 cm, weight: 68.5 ± 11.4 kg). Baseline statistical tests revealed no significant differences between groups ($p > 0.05$).

The average repetitions performed during the high-intensity sets were 13.7 ± 1.3 repetitions, while the low-intensity sets with blood flow restriction averaged 45.2 ± 9.4 repetitions.

For hypertrophy, a main effect of time was found for QCSA at proximal ($F_{[1,16]} = 64.236$, $p = 0.000$, $\eta^{p}_{2} = 0.801$), middle ($F_{[1,16]} = 41.152$, $p = 0.000$, $\eta^{p}_{2} = 0.720$), and distal regions ($F_{[1,16]} = 15.027$, $p = 0.001$, $\eta^{p}_{2} = 0.484$). However, no main effect of group or interaction was revealed (Table 1).

Table 1. Changes in regional quadriceps cross-sectional area

TS (*n*=8)				
Variable	Pre (Mean±SD)	Post (Mean±SD)	change (95%CI)	*d*
QCSA proximal region (mm^2)	6280.00±1075.54	6838.75±1010.53*	558.750 (364.80;752.70)	0.68
QCSA middle region (mm^2)	7692.75 ±1449.16	8341.13±1335.65*	648.38 (243.84;1052.91)	0.62
QCSA distal region (mm^2)	6507.75±1155.69	7012.50±1073.22*	504.75 (233.01;776.49)	0.60
Maximum strength (lbs)	153.75±39.98	195.00±59.52*	41.25 (20.08; 62.41)	0.81
TN (*n*=10)				
Variable	Pre (Mean±SD)	Post (Mean±SD)	change (95%CI)	*d*
QCSA proximal region (mm^2)	5887.90±742.01	6475.20±759.38*	587.30 (339.81;834.79)	0.78
QCSA middle region (mm^2)	7129.30±904.91	7713.70±767.23*	584.40 (347.49;821.31)	0.70
QCSA distal region (mm^2)	5985.00±825.91	6447.60±750.12*	462.60 (4.63;920.57)	0.59
Maximum strength (lbs)	142.00±19.89	170.00±28.67*	28.00 (18.00; 38.00)	1.13
Effect *p*				
	Group	Time	Interaction	
QCSA Proximal region	0.38	0.000	0.88	
QCSA Middle region	0.27	0.000	0.74	
QCSA Distal region	0.23	0.001	0.87	
Maximum strength	0.31	0.000	0.18	

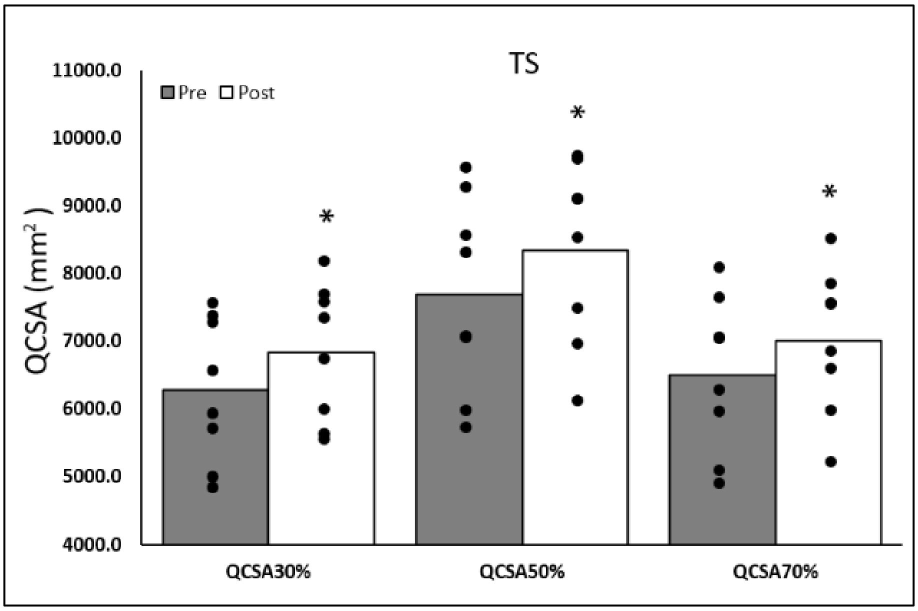
Abbreviation: QCSA = Quadriceps cross-sectional area; TS = Mechanical Tension with Metabolic Stress program; TN = Mechanical Tension program.

* indicated $p < 0.05$ compared to Pre.

Specifically, TS significantly increased QCSA for 8.9% (p = 0.000, ES = *Moderate*), 8.42% (p = 0.007, ES = *Moderate*), and 7.76% (p = 0.003, ES = *Moderate*) from proximal, middle, and distal regions, respectively (Figure 3). In the same way, TN significantly increased QCSA for 9.97% (p = 0.000, ES = *Moderate*), 8.19% (p = 0.000, ES = *Moderate*), and 7.73% (p = 0.048, ES = *Moderate*) from proximal, middle, and distal regions, respectively (Figure 4).

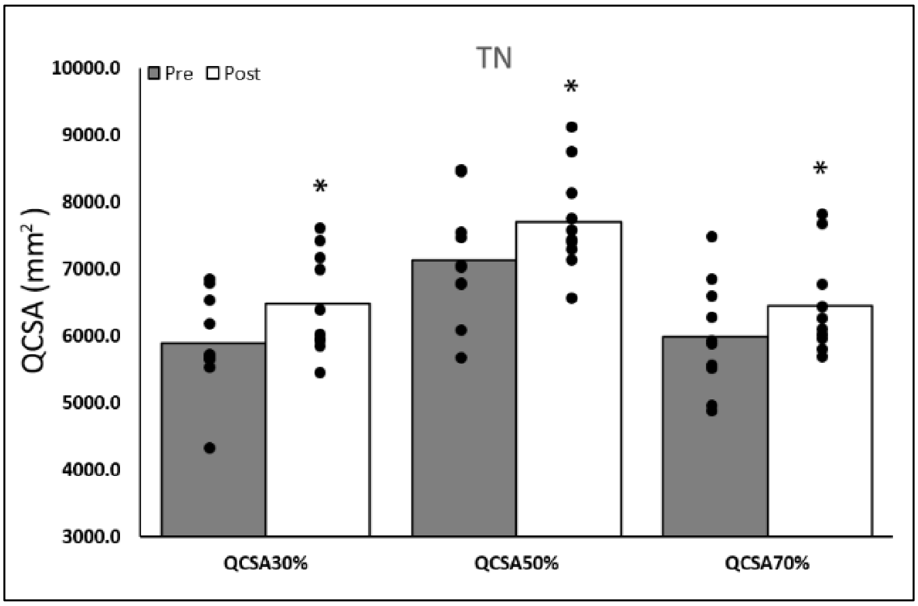
Moreover, a main effect of time of maximum strength was observed ($F_{[1,16]}$ = 54.585, p = 0.000, η_2^p= 0.773). Maximum strength significantly increased for 26.83% (p = 0.002, ES = *Large*) in TS and 19.72% (p = 0.000, ES = *Large*) in TN. Nevertheless, there was no main effects of group or interaction (Table 1).

Besides, Pearson's correlations revealed strong to very strong relationships among QCSA measurements across different regions. Notable positive correlations included QCSA at 30% and 50% (r = 0.90 pre-test, r = 0.87 post-test), 30% and 70% (r = 0.82 pre-test, r = 0.87 post-test), and 50% and 70% (r = 0.93 pre-test, r = 0.94 post-test). All correlations were significant (p = 0.000) (Figure 5).



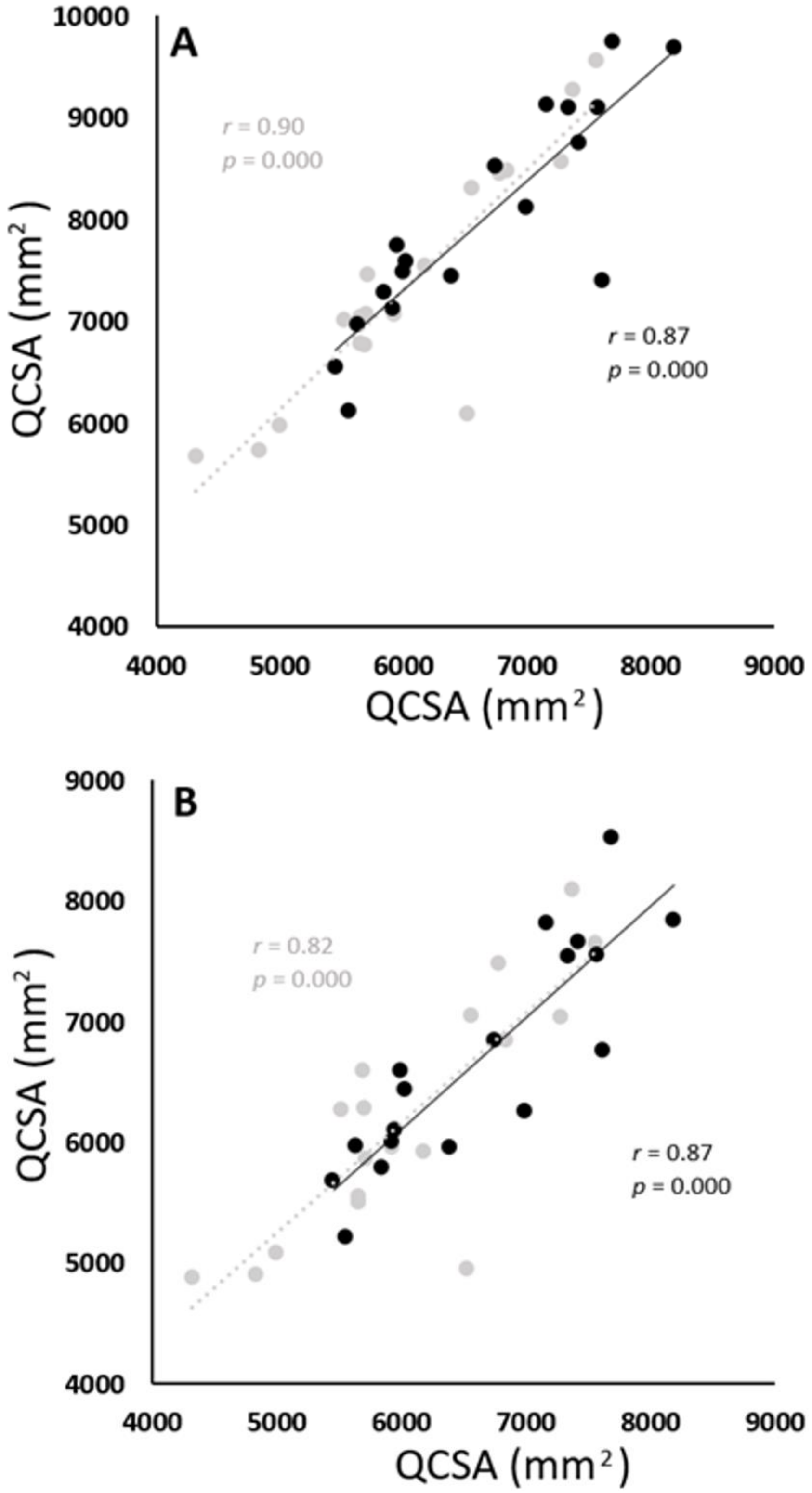
* indicated $p < 0.05$ compared to Pre.

Figure 3. QCSA at proximal, middle, and distal regions in TS group, with individual analyses in black dot



* indicated $p < 0.05$ compared to Pre

Figure 4. QCSA at proximal, middle, and distal regions in TN group, with individual analyses in black dot


A
QCSA (mm²)
10000
9000
8000
7000
6000
5000
4000
r = 0.90
p = 0.000
r = 0.87
p = 0.000
4000
5000
6000
7000
8000
9000
QCSA (mm²)
B
QCSA (mm²)
9000
8000
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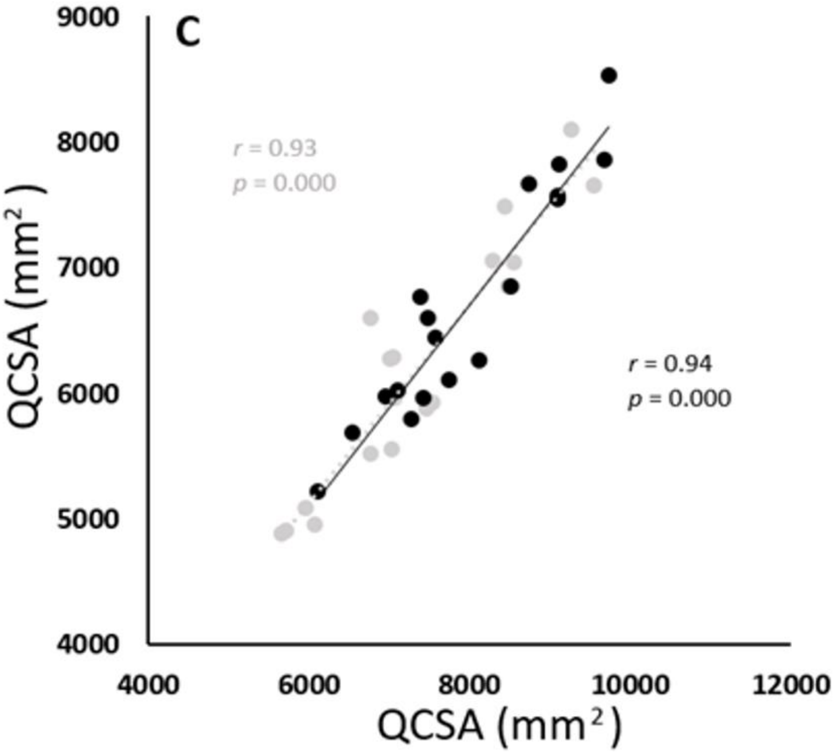
QCSA (mm²)



The dashed line indicated pre-test measurements and the solid black line represented post-test measurements.

Figure 5. Scatter plots showing the relationships between QCSA at proximal and middle regions (A), proximal and distal regions (B), middle and distal regions (C)

4. Discussion

In this study, we demonstrated that both training programs were effective in inducing quadriceps muscle hypertrophy in untrained participants. After training, hypertrophy was observed across regions, with QCSA significantly increasing by about 7-10% in all areas, indicating that the growth was relatively uniform across regions without any specific area showing greater hypertrophy. These findings partially supported the rationale of a previous study, suggesting to investigate muscle hypertrophy across multiple regions rather than relying on a single random region [20]. While we designed the training programs based on the three mechanistic stimuli of hypertrophy [6], our results indicated that both programs produced similar regional hypertrophic outcomes. Therefore, distinct regional hypertrophy may be influenced by factors beyond mechanistic stimuli.

From a physiological standpoint, one possible explanation for the lack of differences between the two training programs (TN and TS) was that, despite differences in training load, both protocols involved lifting to failure [21]. When training to failure – regardless of the intensity of the load – the muscles are pushed to their limit, leading to full recruitment of the motor unit pool [22]. This likely recruited high-threshold motor units, which control fast twitch fibers that had a high hypertrophy potential [23]. During low-intensity training, as metabolites accumulated and fatigue increased, high-threshold motor units were recruited to compensate for the loss of force [24]. This aligned with findings from a previous study, which demonstrated that lifting low loads to failure increased muscle activity, as shown by electromyography (EMG) [25], and stimulated a similar degree of muscle protein synthesis as lifting heavy loads [26]. This may help explain why both high-intensity and low-intensity training with BFR produced comparable increases in muscle cross-sectional area, despite differences in loads and repetition schemes, as both ultimately recruited high-threshold motor units, placing the fibers they control under sufficient tension to stimulate growth [6].

Furthermore, considering training factors, it was proposed in a previous study that more evident regional in a previous study that more evident regional hypertrophy might be influenced by exercise variation [27]. The study showed that performing a variety of exercises, including leg press, half squat, and hack squat machine, caused the vastus lateralis and rectus femoris to hypertrophy in the proximal, middle, and distal regions to different extents compared to performing the leg press alone. Recently, a study found that squatting did not increase rectus femoris CSA in either 25%, 50%, and 75% regions while leg pressing significantly increased rectus femoris CSA in all regions [28].

In our study, we employed only knee extension exercises throughout six weeks of training, despite utilizing progressive set-overload. Therefore, the uniform hypertrophy of quadriceps CSA observed may be a characteristic specific to knee extension exercises, which could lead to similar growth patterns across all regions. Future studies should incorporate a variety of exercises beyond knee extension to determine if hypertrophy patterns differ from those observed in our study, while maintaining a similar number of sets and programming style. This will allow the effect of exercise variation to be determined by controlling these variables [29].

Besides, previous studies that included knee extension in their programs had also investigated quadriceps hypertrophy using MRI to measure QCSA, similar to our approach. For instance, de Souza and the team had examined the effects of leg press, knee extension, and knee flexion exercises across two different training programs, reporting a significant increase in QCSA at the middle region (50%) by approximately 5.5-7.5% after 8 weeks of training [30]. Likewise, another study also found that QCSA at the middle region increased by 3.4% with low-intensity training and 6.5% with high-intensity training after 16 weeks, using exercises like leg press, knee flexion, hip extension, and plantar flexion [31]. Additionally, Laurentino and colleagues used knee extension exercises alone and reported a significant increase in QCSA at the 50% region, ranging from 4.5% to 5% after 8 weeks of training across two different programs [32].

While these previous studies measured changes of QCSA, they primarily focused on the 50% region of the femur length, which may provide a limited view of the overall hypertrophic response, potentially oversimplifying the regional adaptations. Although these findings were valuable, assessing a single region might not fully capture the complexity of muscle growth along the muscle length. In contrast, our study offers a more comprehensive analysis by measuring QCSA at 30%, 50%, and 70% of femur length, providing a broader view of hypertrophy across multiple regions. This approach allows for a more detailed understanding of the regional variations in muscle growth.

Moreover, our current study proved the effectiveness of once-weekly training programs, suggesting that training for only one session per week might be sufficient to induce muscle hypertrophy and muscle strength in untrained practitioners.

This aligned with some previous studies demonstrating the sufficiency of low-frequency training for hypertrophy. For example, Gentil and the team demonstrated that after 10 weeks of training, elbow flexor thickness significantly increased by approximately 5.5% from a once-weekly training program [33]. Similarly, another study demonstrated no statistically significant difference in the hypertrophy of the elbow flexors, elbow extensors, and vastus lateralis between groups training three times per week and those training once per week over an eight-week period [34]. In the same way, Arazi and Asadi showed that resistance training performed only once weekly produced hypertrophic results similar to those seen with two or three weekly sessions [35].

These findings challenged the traditional view of higher-frequency training for optimal hypertrophy [15]. While greater frequency may allow for more total volume, these studies suggest that as long as the total weekly volume is matched, the hypertrophic response may not be significantly different [17]. This could have important implications for individuals with time constraints or those seeking more efficient training schedules [16]. It raises the question of whether hypertrophy can be maximally driven by achieving sufficient intensity and volume in just a once-weekly training program. Future research should explore the impact of different intensities and volumes based on our once-weekly training program to further refine programming strategies to optimize hypertrophy with minimal training frequency.

Additionally, we found that the hypertrophy observed was not only quantitative but also qualitative, as evidenced by a significant increase in muscle strength in both groups (ES = *Large*). We partly attributed these strength gains to the hypertrophic changes. However, it was well established that in the initial weeks of training, most strength improvements were primarily driven by neural adaptations [36], such as increased activation of the agonist muscles [37] and a higher motor unit firing rate [38]. Although we did not directly assess neural adaptations in this study, previous research demonstrated that the voluntary activation of the agonist muscles significantly increased after a few weeks of resistance training [39]. Future studies should investigate the neural effects of the training programs employed here to further validate these findings.

Last but not least, we found strong to very strong correlations among QCSA measurements across different regions (r = 0.82-0.94). These positive relationships suggested a uniform increase in muscle size across all regions following training with knee extension exercises. Consequently, for individuals or researchers with budget constraints, it may not be necessary to measure MRI in every region; however, it is recommended to do so if possible. Instead, assessing just one region could suffice, especially if the training program primarily consists of knee extensions. This approach not only enhances accessibility but also reduces financial barriers in research, making it easier to study hypertrophy without compromising the quality of findings.

5. Conclusions

In conclusion, our study demonstrated that both once-weekly resistance training programs effectively induced quadriceps hypertrophy, as well as resulting in increased maximum strength, in untrained participants. Both training programs resulted in similar hypertrophic patterns, allowing practitioners to choose based on their preferences and highlighting the sufficiency of low-frequency training.

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