THE EFFECTS OF 4 RM AND 10 RM WEIGHT TRAINING PROTOCOLS ON STRENGTH, CROSS-SECTIONAL AREA, AND SPECIFIC TENSION IN UNTRAINED MALES

By

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We accept this thesis as conforming to the required standard

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ABSTRACT

The purpose of this study was to identify and compare the strength, cross-sectional area, specific tension, and anthropometric changes elicited by 4 RM and 10 RM weight training protocols in untrained subjects. 24 males (age 24.2 +/- 1.76 [S.D.] yr, weight 80.4 +/- 13.89 [S.D.] kg) volunteered to participate in this study and were randomly assigned to either the strength group (4 RM), the hypertrophy group (10 RM), or the control group (CG). Training was performed 3 times per week for 10 weeks using free weights to exercise the forearm extensors and flexors. The 4 RM group performed 6 sets of 4 repetitions (reps) to failure, the 10 RM group performed 3 sets of 10 reps to failure, and CG did not train. Strength (1 RM and % increase at training repetition number) was measured at 0, 6, and 10 weeks. Muscle cross-sectional area (magnetic resonance imagery), specific tension (kg/cm^2), relaxed and flexed girth (circumference), and sum of skinfolds (bicep and tricep) of the arm were measured at 0 and 10 weeks. There was no change in any of the dependent variables in the control group during the 10 week period of the study. Significant ($p<0.05$) increases in both forearm extensor and flexor 1 RM strength, % strength at training repetition number, muscle cross-sectional area, specific tension, and flexed girth occurred in both 4 RM and 10 RM groups. There were no differences between the two groups. No changes in relaxed girth or sum of skinfolds occurred in either group. The 4 RM and 10 RM loading intensities elicited significant and equal increases in strength, cross-sectional area, specific tension, and flexed girth. These results suggest that 4 RM and 10 RM weight training protocols produce similar neuromuscular adaptations in previously untrained subjects.

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TABLE OF CONTENTS

List of Tables

List of Figures

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I would also like to thank St. Michaels University School for providing me with a houseparent position and extending me computer and photocopying privileges.

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Dedication

To my mother Arlene who always made sure I had everything I wanted even before she had what she needed. She has shown me the true meaning of both love and unselfishness and I cannot begin to describe the positive influence her support has had on my life. Thanks mom.

"Study and in general the pursuit of truth and beauty is a sphere of activity in which we are permitted to remain children all our lives."

Albert Einstein

INTRODUCTION

The neuromuscular adaptations to resistance training include muscle hypertrophy and increased neural drive, both of which are associated with increases in muscular strength (Kraemer, Deschenes, & Fleck, 1988; McDonagh & Davies, 1984; Moritani & DeVries, 1979; Sale, 1992; Tesch, 1988). Muscle hypertrophy is the result of an increase in the cross-sectional area (CSA) of individual muscle fibres which causes a concomitant increase in whole muscle CSA (Goldspink, 1992; MacDougall, 1992). This increase in muscle CSA can, in turn, result in an increase in lean body mass (Hakkinen, Komi, & Tesch, 1981; Katch, Katch, Moffatt, and Gittleson, 1980; Tesch, 1992; Tesch, 1988). Increased neural drive is the result of an increase in the ability of the nervous system to recruit the available muscle mass (Sale, 1992). This is considered to be the result of one or more of the following adaptations: an increase in the number of motor units recruited; an increase in the firing frequency of motor units recruited; an increase in the synchronization of motor unit firing; and/or a decrease in inhibitory or protective mechanisms (Sale, 1992).

Depending on current muscle CSA and/or strength status, individuals may have different needs with respect to neuromuscular adaptations from resistance training. Some individuals may require concurrent increases in both muscle CSA and strength. However, other individuals may need an increase in strength without an increase in muscle CSA because an increase in CSA would be disadvantageous to performance in their sport. Athletes, coaches, trainers, and therapists require resistance training programs which meet specific muscular strength and/or CSA needs. Therefore, it is important to determine the training methods that are most effective in eliciting increases in muscle CSA and strength and, furthermore, whether or not increases in strength can be elicited without a concurrent hypertrophic response.

It has been suggested that it is possible to increase strength as a result of neural adaptations without a corresponding increase in muscle CSA (Hakkinen, Komi, Alen, & Kauhanen, 1987; Moritani & DeVries, 1979; Narici, Roi, Landoni, Minetti, & Cerretelli, 1989). Significant increases in strength with concomitant significant increases in neural drive in the form of either increased integrated electromyograpgh (iEMG) activity or increases in specific tension (force generated per unit of muscle area) have been found (Hakkinen et al., 1987; Moritani & DeVries, 1979; Komi, Viitasalo, Rauramaa, & Vihko, 1978; Narici et al.,1989). It has also been reported that up to 60% of measured increases in strength could not be accounted for by muscle hypertrophy (Moritani & DeVries, 1979; Narici et al., 1989). Strength gains which cannot be accounted for by increased muscle CSA and increases in iEMG activity and/or specific tension have been interpreted as evidence of neural adaptation (Hakkinen & Komi, 1983; Hakkinen, 1989; Komi et al., 1978; Moritani & DeVries, 1979; Narici et al., 1989).

Hakkinen & Keskinen (1989) compared elite powerlifters to elite endurance athletes and reported that specific tension was significantly greater in the powerlifters. This suggests that heavy resistance training can increase the force generating capability of muscle per unit of area. Being able to increase the force generating capability per unit of area further implies that strength can be increased through resistance training without evoking a hypertrophic response. In addition, Hakkinen, Komi, Alen, and Kauhanen (1987) reported that in elite power lifters a high loading intensity of approximately 1-3 RM elicited increases in both strength and integrated EMG activity without increases in muscle CSA. A loading intensity of approximately 10 RM did not increase strength or integrated EMG activity. Consequently, in order to elicit neural adaptations and increase strength without a corresponding increase in muscle CSA, resistance training programs consisting of high loads (85-90% 1 RM) and very few repetitions (1-4) have been recommended (Garhammer & Takano, 1992; Poliquin, 1991; Schmidtbleicher, 1985).

Significant increases in strength have also been elicited with concomitant significant increases in muscle fibre or whole muscle CSA (Gonyea & Sale, 1982; MacDougall, Elder, Sale, Moroz, & Sutton, 1980; Narici et al., 1989). In these cases it has generally been reported that the increases in strength are due primarily to increases in muscle CSA with neural adaptations contributing in the early weeks of the program and diminishing after approximately the sixth week (Hakkinen & Komi, 1983; Hakkinen, 1989; Moritani & DeVries, 1979). MacDougall (1992) implied that further evidence of resistance training eliciting a hypertrophic response is provided by the findings that strength trained individuals possess larger muscle CSA values than untrained individuals. Training programs consisting of moderate loads (70-75% 1 RM) and a moderate number of repetitions (10-12) have been recommended to maximize the stimulation of muscle hypertrophy (Poliquin, 1988; Poliquin, 1990; Poliquin, 1991; Schmidtbleicher, 1985; Stone, O'Bryant, & Garhammer, 1981; Tesch, 1992). Although there is no scientific proof that this training protocol is the most effective, there is indirect support for this training recommendation. Kraemer, Gordon, Fleck, Marchitelli, Mello, Dziados, Friedl, and Harman (1991) reported that a 10 RM loading intensity was superior to a 5 RM loading intensity for increasing serum growth hormone concentration. Also, the fact that bodybuilders possess great amounts of lean body mass from training with this type of protocol suggests that it is effective for producing increases in muscle CSA (Katch, Katch, Moffat, & Gittleson, 1980).

Although resistance training has been reported to elicit both hypertrophic and neural adaptations, the issue regarding if and how these neuromuscular adaptations can be elicited independently has received little attention from exercise scientists and is not well understood. There are strongly held beliefs among practitioners and some scientists regarding the best training methods for eliciting hypertrophic and/or neural adaptations but these beliefs are based either on experience or inconclusive scientific data. The purpose of this study was to identify and compare the strength, cross-sectional area, specific tension, and anthropometric changes elicited by loading intensities typically recommended in the literature for increasing strength without a hypertrophic response (4 RM) and increasing muscle CSA (10 RM).

STATEMENT OF THE PROBLEM

There were three major problems:

1. To identify the hypertrophic, specific tension, anthropometric and strength performance effects of a 4 RM resistance training program (6 sets of 4 repetitions @ ~ 85% 1 RM) on forearm extensors and flexors in untrained subjects.

   Specific Objectives

   - To identify the effects of this program on muscle cross-sectional area.
   - To identify the effects of this program on specific tension.
   - To identify the effects of this program on flexed girth, relaxed girth, and sum of skinfolds.
   - To indentify the effects of this program on 1 RM and 4 RM strength.

2. To identify the hypertrophic, specific tension, anthropometric and strength performance effects of a 10 RM resistance training program (3 sets of 10 repetitions @ ~ 70% 1 RM) on forearm extensors and flexors in untrained subjects.

   Specific Objectives

   - To identify the effects of this program on muscle cross-sectional area.
   - To identify the effects of this program on specific tension.
   - To identify the effects of this program on flexed girth, relaxed girth, and sum of skinfolds.
   - To indentify the effects of this program on 1 RM and 10 RM strength.

3. To determine if the hypertrophic, specific tension, anthropometric and strength performance effects of the 4 RM and 10 RM resistance training programs on forearm extensors and flexors in untrained subjects were significantly different.

Specific Objectives

- To determine if the effects of these programs on muscle cross-sectional area were significantly different.
- To determine if the effects of these programs on specific tension were significantly different.
- To determine if the effects of these programs on flexed girth, relaxed girth, and sum of skinfolds were significantly different.
- To determine if the effects of these programs on 1 RM and training repetition number (4 RM or 10 RM) strength were significantly different.

HYPOTHESES

The following null hypotheses were tested:

H_0 1: The 10 week 4 RM resistance training program will have no significant effect on muscle CSA.

H_0 2: The 10 week 4 RM resistance training program will have no significant effect on specific tension.

H_0 3: The 10 week 4 RM resistance training program will have no significant effect on the following anthropometric variables:

H_0 3a: Flexed girth of forearm extensors and flexors

H_0 3b: Relaxed girth of forearm extensors and flexors

H_0 3c: Sum of skinfolds of forearm extensors and flexors

H_0 4: The 10 week 4 RM resistance training program will have no significant effect on the following strength variables:

H_0 4a: 1 RM forearm extensor strength

H_0 4b: 1 RM forearm flexor strength

H_0 4c: 4 RM forearm extensor strength

H_0 4d: 4 RM forearm flexor strength

H_0 5: The 10 week 10 RM resistance training program will have no significant effect on muscle CSA.

H_0 6: The 10 week 10 RM resistance training program will have no significant effect on specific tension.

H_0 7: The 10 week 10 RM resistance training program will have no significant effect on the following anthropometric variables:

- **H_0 7a**: Flexed girth of forearm extensors and flexors
- **H_0 7b**: Relaxed girth of forearm extensors and flexors
- **H_0 7c**: Sum of skinfolds of forearm extensors and flexors

H_0 8: The 10 week 10 RM resistance training program will have no significant effect on the following strength variables:

- **H_0 8a**: 1 RM forearm extensor strength
- **H_0 8b**: 1 RM forearm flexor strength
- **H_0 8c**: 10 RM forearm extensor strength
- **H_0 8d**: 10 RM forearm flexor strength

H_0 9: No difference will exist between the effects of the 4 RM and 10 RM training programs on muscle CSA.

H_0 10: No difference will exist between the effects of the 4 RM and 10 RM training programs on specific tension.

H_0 11: No difference will exist between the effects of the 4 RM and 10 RM training programs on the following anthropometric variables:

- **H_0 11a**: Flexed girth of forearm extensors and flexors
- **H_0 11b**: Relaxed girth of forearm extensors and flexors
- **H_0 11c**: Sum of skinfolds of forearm extensors and flexors

H_0 12: No difference will exist between the effects of the 4 RM and 10 RM training programs on the following strength variables:

H_0 12a: 1 RM forearm extensor strength

H_0 12b: 1 RM forearm flexor strength

H_0 12c: 4 RM and 10 RM forearm extensor strength

H_0 12d: 4 RM and10 RM forearm flexor strength

ASSUMPTIONS

1. The training protocols will elicit measurable increases in muscle CSA and/or strength.
2. The study is of sufficient duration for adaptations to occur.
3. The study is of sufficient duration to allow possible differences between the two training protocols to emerge.

DELIMITATIONS

1. Due to budget restraints only pre-training and post-training CSA measurements were taken. Consequently, pre to mid and mid to post-training comparisons between the two groups on CSA and specific tension were not possible.
2. Also due to budget restraints, only 5 control subjects were included. This small 'N' of the control group could have affected the validity of statistical analyses on this group.
3. Untrained subjects were used. Untrained subjects may respond generically to different types of training whereas trained subjects may not; this limited the generalizability of results.
4. The desired repetition number may not have always corresponded to the percent of 1 RM predicted; this could have caused differences in training volume.

LIMITATIONS

1. Subjects may have had different percentages of fibre types and therefore may have responded differently to training.
2. Subjects may not have followed training protocols.

OPERATIONAL DEFINITIONS

1 RM:

The maximum amount of weight which can be lifted for one repetition (Tesch, 1992).

4 RM:

The maximum amount of weight which can be lifted for 4 repetitions.

10 RM:

The maximum amount of weight which can be lifted for 10 repetitions.

Failure:

When fatigue will not allow another repetition to be completed using the technique outlined in the methodology (Tesch, 1992).

Forearm Flexors:

Biceps brachii, biceps brachialis and brachioradialis.

Forearm Extensors:

Triceps brachii.

Loading Intensity:

The amount of load being lifted relative to an individual's 1 RM or the number of repetitions performed before failure. An 85% loading intensity refers to a load that corresponds to 85% of an individual's 1 RM. A 4 RM loading intensity refers to a load that induces failure after 4 repetitions (Tesch, 1992). According to the 1 RM continuum, 70% 1 RM and 85% 1 RM correspond to approximately 10 and 4 repetitions, respectively (Kraemer et al., 1992; McDonagh & Davies, 1984; Poliquin, 1990.

Repetitions:

The number of times a weight is lifted consecutively without rest (Poliquin, 1988).

RM:

Repetition Maximum. The maximum load which can be lifted for a given number of repetitions. 4 RM refers to the maximum load which can be lifted for 4 repetitions (Tesch, 1992).

Set:

The unit consisting of the number of repetitions performed consecutively (Poliquin, 1988).

Specific Tension:

The force generated per unit of muscle area (kg/cm^2) [Garfinkel & Cafarelli, 1992; Narici et al., 1989].

Strength:

In the present study strength was defined as the maximum weight which could be lifted for 1, 4, or 10 repetitions (1RM, 4 RM, 10 RM).

Training Volume:

In the present study training volume was defined as the amount of work done in a single workout. Volume was determined by the following formula: repetitions x sets x load (Poliquin, 1988). The 4 RM and 10 RM groups were equated for volume. Load, as previously defined, was determined according to the 1 RM continuum and was relative to each individual's 1 RM. Each subject in the 4 RM or 10 RM group trained with a load corresponding to approximately 85% or 70% of his individual 1 RM, respectively.

METHODS

Subjects

24 male university students (age 24.2 +/- 1.76 [SD] yr, weight 80.4 +/- 13.89 [SD] kg) volunteered to serve as subjects for this study. Initially, because of financial constraints, a control group was not included. However, after the initial M.R.I. scans of the original 24 training subjects it was determined that a control group (CG) containing 5 subjects would be financially feasible and was therefore added. These subjects were also volunteers and were tested using the same methods as the training subjects. The only differences between the control group (CG) and the two training groups were that, because of financial contraints, (CG) contained only 5 subjects and, because they were added after the other two groups, these subjects were not able to be randomly assigned. Originally 24 subjects volunteered to serve as training subjects. However, citing other commitments, 5 exercised their right to stop participating. This left a total of 24 subjects, 19 training subjects and 5 control subjects. All subjects were oriented to the training and testing protocols before signing informed consent forms and agreeing to participate (Appendix A). The subjects were considered untrained as they had never followed a regimented weight training program and had not participated in any weight training for at least one year. Training subjects were randomly assigned to either the high loading intensity strength group (4 RM) or the medium loading intensity hypertrophy group (10 RM).

Training

Training was performed 3 times per week for 10 weeks. Training sessions consisted of the following core exercises performed in this order: tricep bench press (curling bar), tricep pulley press-downs (straight handle), standing bicep barbell curls (olympic bar), and standing simultaneous dumbell curls. Subjects also wanted to perform some exercises for the other major upper body muscles so supplemental exercises were added. These exercises were performed with less sets to prevent the duration of the workouts from becoming too long. Supplemental exercises were performed in the following order after the core exercises had been completed: bench press, bench pulls, and shoulder press. The (4 RM) group performed 6 sets of 4 repetitions (~ 85% 1 RM) to failure for the core exercises and two sets of 4 repetitions to failure for the supplemental exercises. The (10 RM) group performed 3 sets of 10 repetitions (~ 70% 1 RM) to failure for the core exercises and 1 set of 10 repetitions to failure for each of the supplemental exercises. The (4 RM) and (10 RM) groups trained with different loading intensities (85% 1 RM and 70% 1 RM, respectively) but were equated approximately for volume (reps X sets X load). According to the 1 RM continuum a 4 RM load corresponds to approximately 85% of an individual's 1 RM and a 10 RM load corresponds to approximately 70% of an individual's 1 RM (Kraemer et al., 1992; McDonagh & Davies, 1984; Poliquin, 1990). The volume of work performed by the subjects in the 4 RM group was therefore (4 repetitions) x (6 sets) x (85% of each individual's 1 RM) which equalled 20.4 units of work. The volume of work performed by the subjects in the 10 RM group was (10 repetitions) x (3 sets) x (70% of each individual's 1 RM) which equalled 21.0 units of work. The supplemental exercises were also equated for volume. Between each set there was either a 3 minute rest period (4 RM) or a two minute rest period (10 RM) and there was a minimum of 48 hours rest between workouts. Throughout the training period the loads were monitored and increased when necessary in order to ensure that prescribed loading intensities were maintained (i.e. ensuring failure at desired repetition number).

The control group (CG) did not train during the study.

Testing

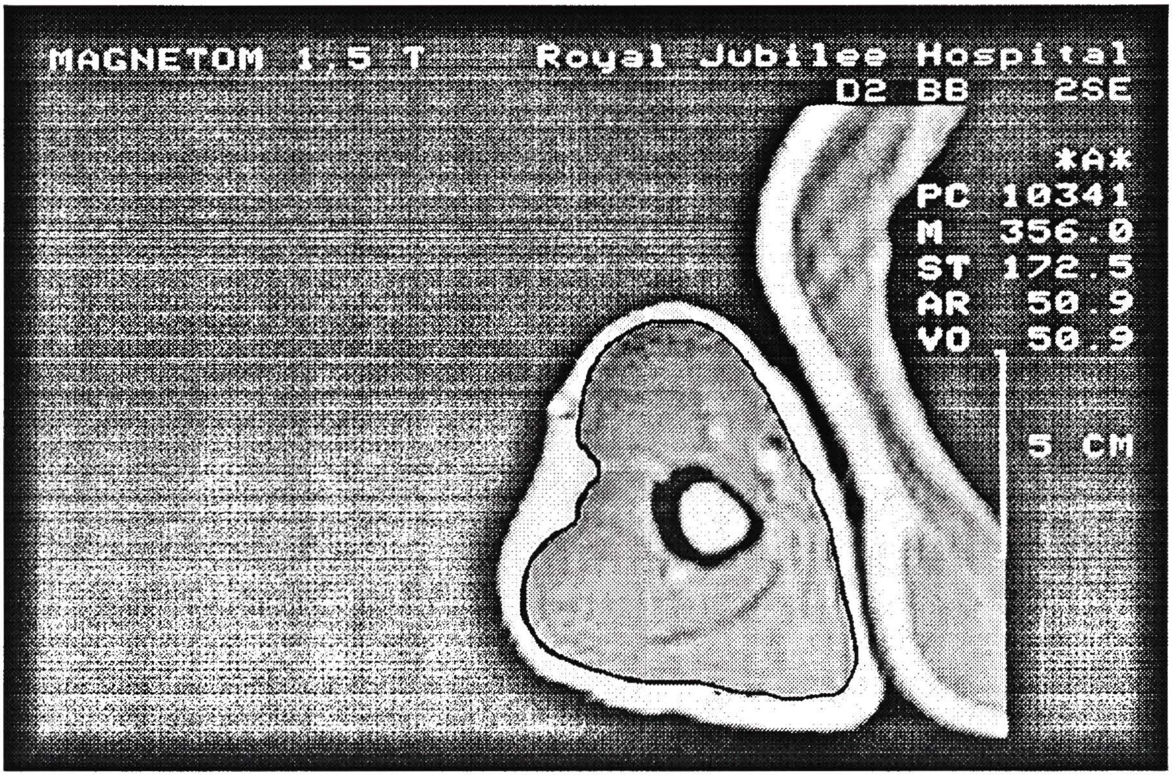
Strength

Strength was measured using free weights to determine one repetition maximum (1 RM) values for the tricep bench press and standing bicep curl. % strength increases at training repetition number (4 and 10 for 4 RM and 10 RM groups, respectively) were also determined. Strength values were measured at the beginning of week 0, the end of week 6, and the end of week 10. Prior to testing, subjects warmed-up by completing one set of 15 repetitions at ~25 RM, one set of 10 repetitions at ~ 15 RM, and one set of 5 repetitions at ~ 10 RM. There were 4 minute rest periods between both warm-up and testing sets. 1 RM values were determined by having the subjects attempt successive sets of single repetitions of increasing weight (Kraemer, et al., 1991). When it was determined that a maximal value had been reached the bar was taken to a beam scale and weighed. The strength at training repetition number (4 and 10 for 4 RM and 10 RM groups, respectively) values were determined by weighing the bar that the subjects were using for their 4 RM or 10 RM training. The strength increases at training repetition number were then calculated into % increases. The tricep bench press 1 RM test was performed with the subject lying on the bench keeping head, shoulder blades, and buttocks in contact with the bench at all times. Both feet remained flat on the floor shoulder width apart. The test began with the bar grasped at nipple width resting on the subject's chest at nipple level and was considered successful only if elbows were locked at the top of the lift. Barbell curl testing was performed with the subject standing with shoulder blades and buttocks against a wall at all times. Subject's knees were kept slightly bent and feet were shoulder width apart. The bar was grasped with hands shoulder width apart and the test began with the bar resting on the thighs with arms fully extended (elbows locked). A lift was considered successful if the elbows were brought to full flexion.

Muscle Cross-Sectional Area (CSA)

Muscle CSA was determined by magnetic resonance imagery (Siemens Magnetom 1.5 T). Repetition time and echo time were set at 200 and 20 ms, respectively, and slice/scan thickness was set at 10 mm. All scans and measurements were of the right arm. Coronal scans were used to establish both humeral length and midpoint. After the midpoint of the humerus was determined, three axial scans were taken; one at midpoint, one 15% of total humeral length proximal to midpoint, and one 15% of total humeral length distal to midpoint. It was later discovered that in the proximal scan of some subjects it was not possible to differentiate between shoulder and arm musculature. For this reason only the midpoint and distal scans were measured. Because of the difficulty in delineating the individual muscles of the arm, the CSA of the entire forearm extensor and flexor groups was measured. The extensor group contained the three heads of the triceps brachii and the flexor group consisted of the biceps brachii and brachialis muscles as well as the brachioradialis. CSA was determined by using the "area" function of the MRI computer program. Each image was displayed on the computer screen and the outlines of the forearm extensor and flexor muscles were traced (Fig 1). The computer then calculated the area of the outlined image. Because the CSA values included the bone, the area of the bone was also calculated and subtracted from the initial CSA figure. During a pilot study, test-retest reliability for repeated CSA measurements was 0.998.

Figure 1. Axial magnetic resonance imaging (M.R.I.) scan of right forearm extensor and flexor muscles. Scan has been traced and the computer has calculated cross-sectional area (AR).


MAGNETOM 1,5 T
Royal Jubilee Hospital
D2 BB 2SE
A
PC 10341
M 356.0
ST 172.5
AR 50.9
VO 50.9
5 CM

Specific Tension

Specific Tension (kg/cm^2) was determined by dividing the combined 1 RM tricep press and 1 RM barbell curl scores (kg) by the CSA values (cm^2) at both midpoint and distal axial scans (Garfinkel & Cafarelli, 1992; McDonagh & Davies, 1984; Narici et al., 1989). For example, pre-intervention specific tension was calculated by combining pre-intervention 1 RM tricep press and 1 RM barbell curl scores (kg) and dividing this sum by the CSA values from first the midpoint axial scan (pre-intervention midpoint specific tension) and then the distal axial scan (pre-intervention distal specific tension). Post-intervention specific tension was calculated in the same way using the post-intervention values for 1 RM tricep press and barbell curl and midpoint and distal CSA.

Anthropometrics

Girth measurements were determined for both relaxed and flexed positions of the right arm. For the relaxed girth measurement the subjects stood with arms relaxed at the sides. Measurements were taken at the point midway between the tip of the acromion and the tip of the olecranon. Flexed girth was determined by measuring at the point of largest circumference. Subjects stood with humerus parallel to the ground, elbow bent at 90 degrees, and wrist flexed. Girths were corrected for forearm extensor and flexor skinfolds as outlined in the Canadian Standardized Test of Fitness Operations Manual (1986).

Statistical Analysis

An initial analysis of variance for repeated measures was conducted to determine if the training programs produced group, time, and/or group by time interaction changes in the dependent variables. Independent t-tests and t-tests for paired samples were then conducted to determine differences within and between group means. Significance was set at $p < 0.05$.

RESULTS

There was no initial difference in any of the dependent variables among the three groups. There was no change in any of the dependent variables in the control group during the 10 week period of the study.

Cross-Sectional Area (CSA)

Cross-sectional area (CSA) data for both midpoint and distal measurements are presented in Table 1 and in Figures 2 and 3, respectively. Significant increases occurred at both the midpoint (F 1,21 = 36.01, $p<0.01$) and distal (F 1,21 = 19.41, $p<0.01$) cross-sectional measurements in both the 4 RM and 10 RM groups. There was no difference between the two training groups.

Strength

1 RM measurements for forearm extension and flexion are presented in Table 2 and in Figures 4, 5, 6 and 7. Significant increases in extensor (F 1,21 = 58.53, $p<0.01$) and flexor (F 1,21 = 53.30, $p<0.01$) strength occurred in both the 4 RM and 10 RM groups between pre-training and post-training. Significant increases in forearm extensor (F 2,34 = 73.23, $p<0.01$) and flexor (F 2,34 = 59.03, $p<0.01$) strength also occurred between pre-training and mid-training (week 0 and week 6) and mid-training and post-training (week 6 and week 10) periods. There was no significant difference in the amount of strength increase from pre-training to mid-training and mid-training to post-training. There was no difference between groups.

Strength data for % change for forearm extensor and flexor strength at training repetition number (4 or 10) are presented in Table 3 and in Figures 8 and 9, respectively. Both 4

RM and 10 RM groups showed significant % increases in forearm extensor (F 2,34 = 134.48, $p<0.01$) and flexor (F 2,34 = 73.29, $p<0.01$) strength at their respective training repetition numbers (4 and 10). Significant changes occurred between both pre-training to mid-training and mid-training to post-training measurements; there was no difference in the amount of strength increase between groups. A significantly greater % increase in forearm extensor strength occurred during the pre-training to mid-training period compared to the mid-training to post-training period in the 4 RM group. This pattern was also present in the 10 RM group but the difference was not significant. Both training groups displayed significantly greater % increases in forearm flexor strength during the pre-training to mid-training period compared to the mid-training to post-training period.

Specific Tension

Specific tension data for both midpoint and distal measurements are presented in Table 4 and in Figures 10 and 11, respectively. Significant increases in specific tension at both midpoint (F 1,21 = 12.71, $p<0.05$) and distal (F 1,21 = 26.47, $p<0.05$) measurements were observed in both the 4 RM and the 10 RM groups. There was no difference between the two training groups.

Anthropometrics

Data for relaxed girth, flexed girth, and sum of skinfolds (SOS) are presented in Table 5. Flexed girth data is also displayed in Figure 12. Significant increases (F 1,20 = 13.64, ($p<0.05$) in flexed girth occured in both training groups; there was no difference between groups. There were no differences between pre-training and post-training values for relaxed girth or SOS in any group.

Table 1:

Mean (SE) pre-training and post-training midpoint and distal CSA values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups.

Group	Midpoint CSA (cm^2)	Distal CSA (cm^2)
Control		
pre	46.5 (5.3)	43.9 (5.0)
post	46.4 (5.2)	44.0 (5.0)
4 RM		
pre	49.0 (2.2)	48.4 (2.8)
post	*53.1 (2.4)	*51.4 (2.7)
10 RM		
pre	49.5 (3.0)	47.7 (2.6)
post	*53.4 (2.8)	*50.9 (2.3)

Note: * represents significant difference between pre-training and post- training values ($p < 0.05$).

Figure 2. Mean (SE) pre-training and post-training midpoint CSA values for control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups. * represents significant difference between pre-training and post-training values.

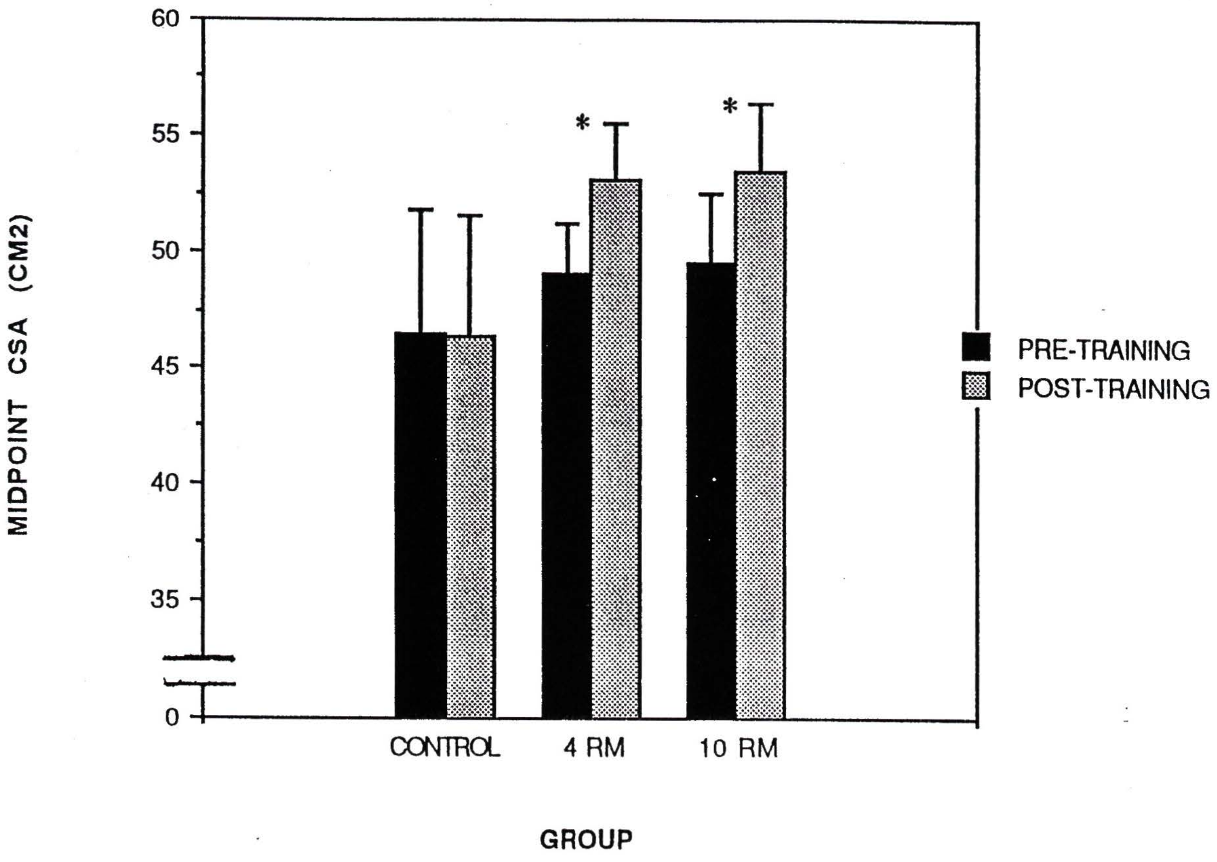

MIDPOINT CSA (CM2)
60
55
50
45
40
35
0
*
*
PRE-TRAINING
POST-TRAINING
CONTROL
4 RM
10 RM
GROUP

Figure 3. Mean (SE) pre-training and post-training distal CSA values for control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups. * represents significant difference between pre-training and post-training values.

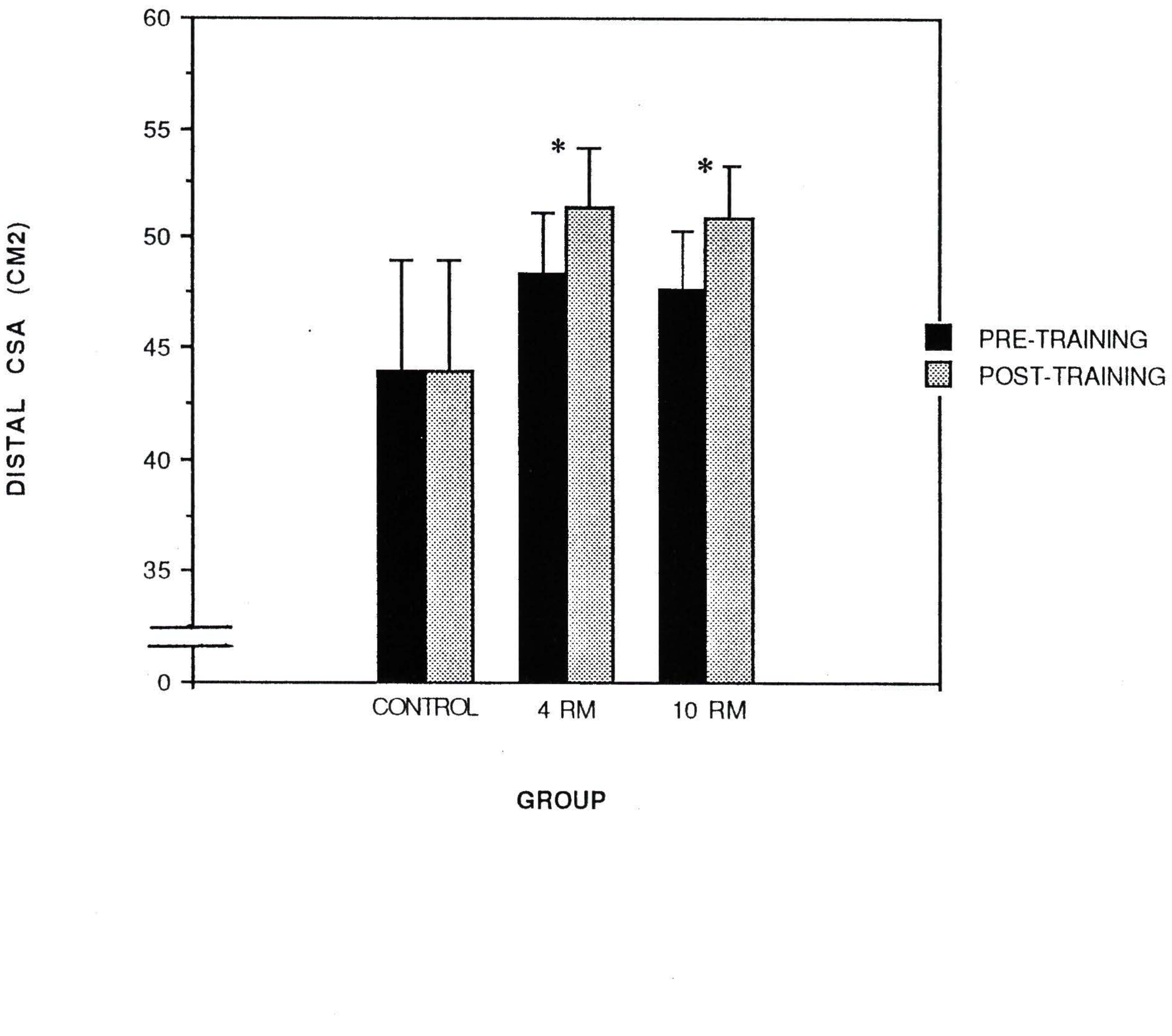

DISTAL CSA (CM2)
60
55
50
45
40
35
0
*
*
CONTROL
4 RM
10 RM
GROUP
PRE-TRAINING
POST-TRAINING

Table 2:

Mean (SE) 1 RM pre-training, mid-training and post-training forearm extensor and flexor strength values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups.

Group	1RM Extensor Strength (kg)	1RM Flexor Strength (kg)
Control		
pre	67.4 (5.5)	40.4 (3.9)
post	67.9 (5.3)	41.2 (3.6)
4 RM		
pre	78.7 (5.3)	44.4 (2.3)
mid	*86.6 (5.7)	*48.2 (1.7)
post	*92.0 (5.6)	*50.5 (1.8)
10 RM		
pre	70.2 (4.7)	43.4 (2.5)
mid	*77.3 (4.7)	*46.3 (2.3)
post	*82.9 (5.1)	*48.0 (2.2)

Note: * represents significant difference from previous value ($p < 0.05$).

Figure 4. Mean (SE) 1 RM pre-training and post-training forearm extensor strength values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups. * represents significant difference from previous value.

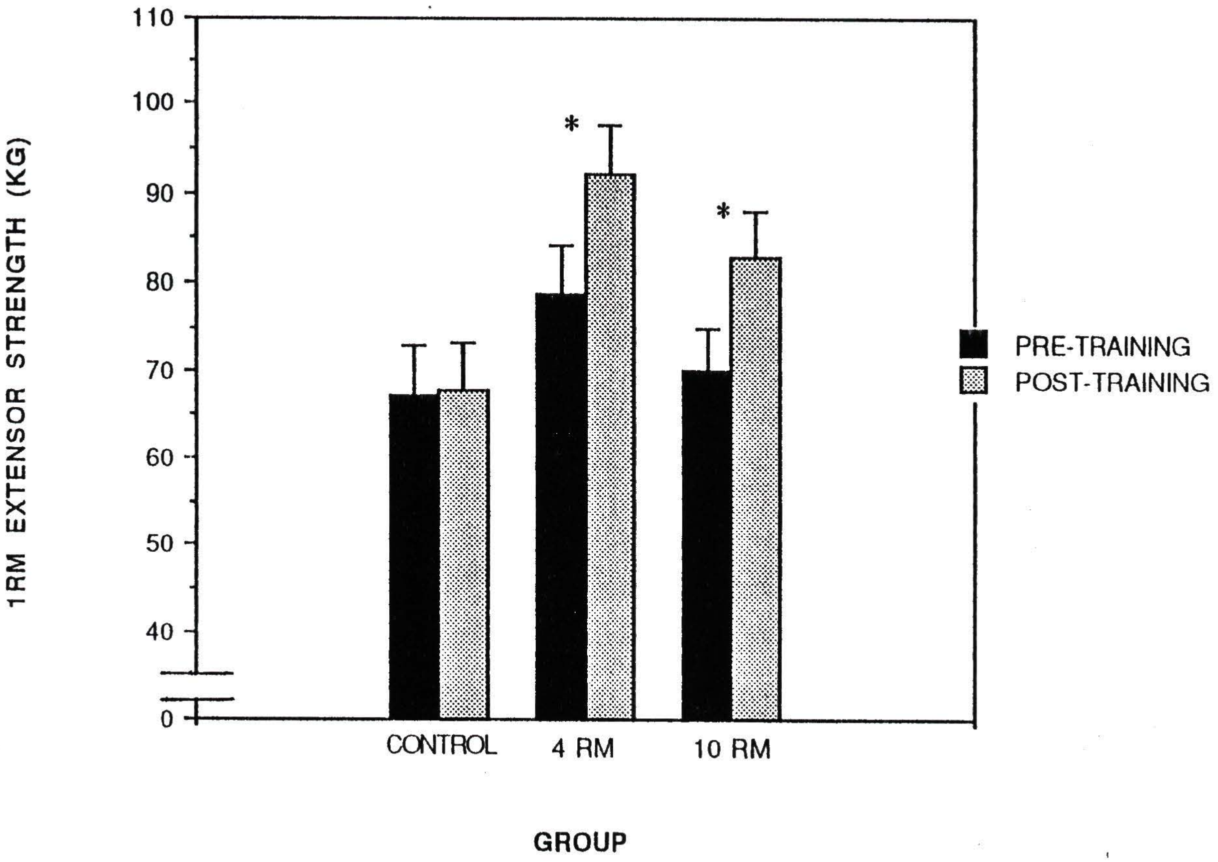

110
100
90
80
70
60
50
40
0
1RM EXTENSOR STRENGTH (KG)
*
*
CONTROL
4 RM
10 RM
GROUP
PRE-TRAINING
POST-TRAINING

Figure 5. Mean (SE) 1 RM pre-training, mid-training, and post-training forearm extensor strength values of 4 RM (N = 10) and 10 RM (N = 9) groups. * represents significant difference from previous value.

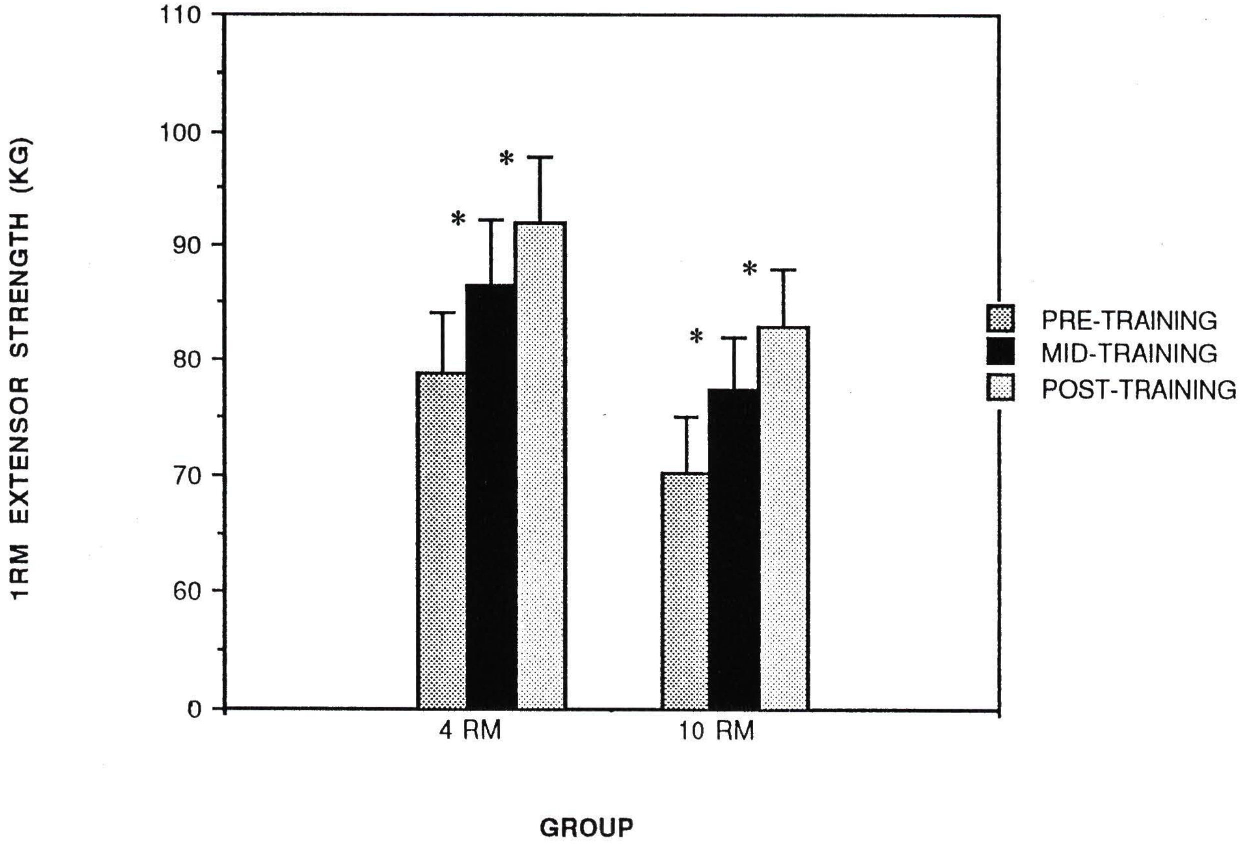

110
100
90
80
70
60
0
1RM EXTENSOR STRENGTH (KG)
*
*
*
*
4 RM
10 RM
GROUP
PRE-TRAINING
MID-TRAINING
POST-TRAINING

Figure 6. Mean (SE) 1 RM pre-training and post-training forearm flexor strength values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups. * represents significant difference from previous value.

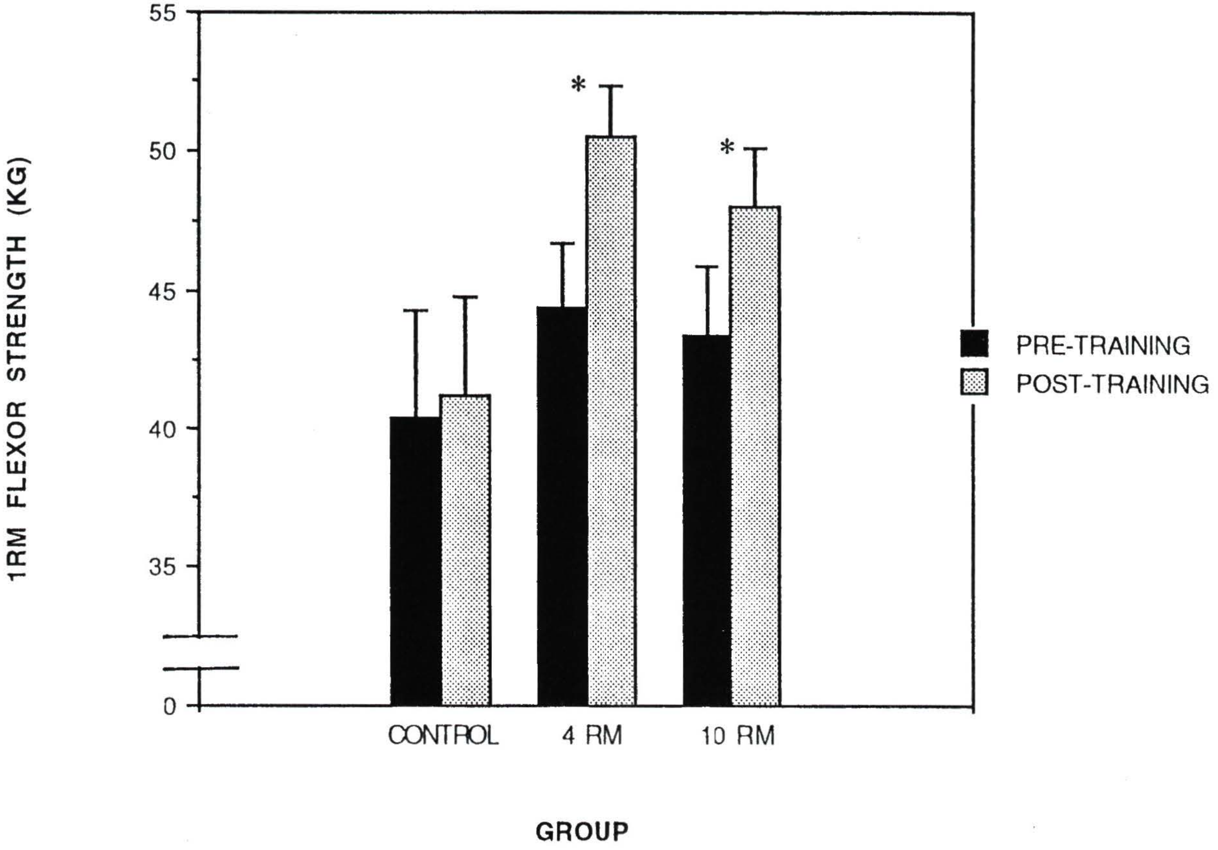

1RM FLEXOR STRENGTH (KG)
55
50
45
40
35
0
*
*
CONTROL
4 RM
10 RM
GROUP
PRE-TRAINING
POST-TRAINING

Figure 7. Mean (SE) 1 RM pre-training, mid-training, and post-training forearm flexor strength values of 4 RM (N = 10) and 10 RM (N = 9) groups. * represents significant difference from previous value.

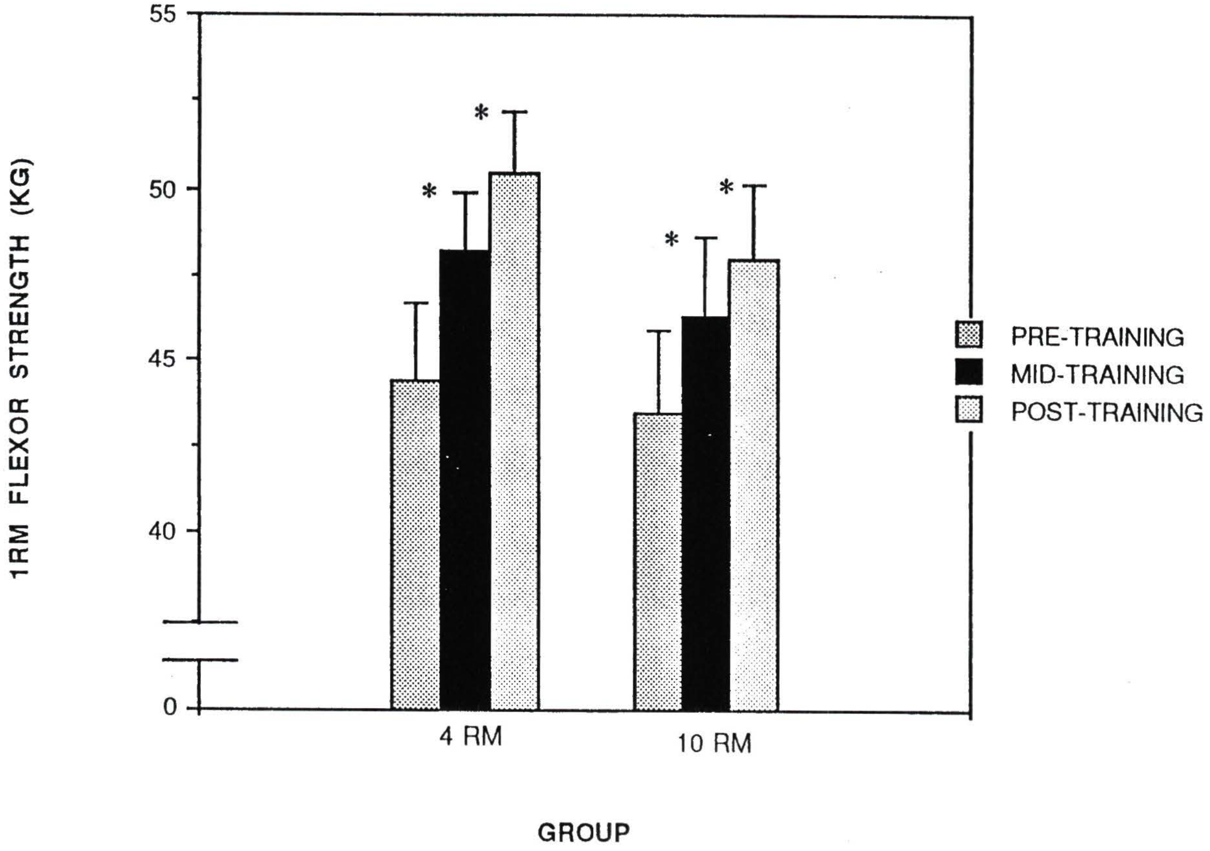

55
50
45
40
0
1RM FLEXOR STRENGTH (KG)
*
*
*
*
4 RM
10 RM
GROUP
PRE-TRAINING
MID-TRAINING
POST-TRAINING

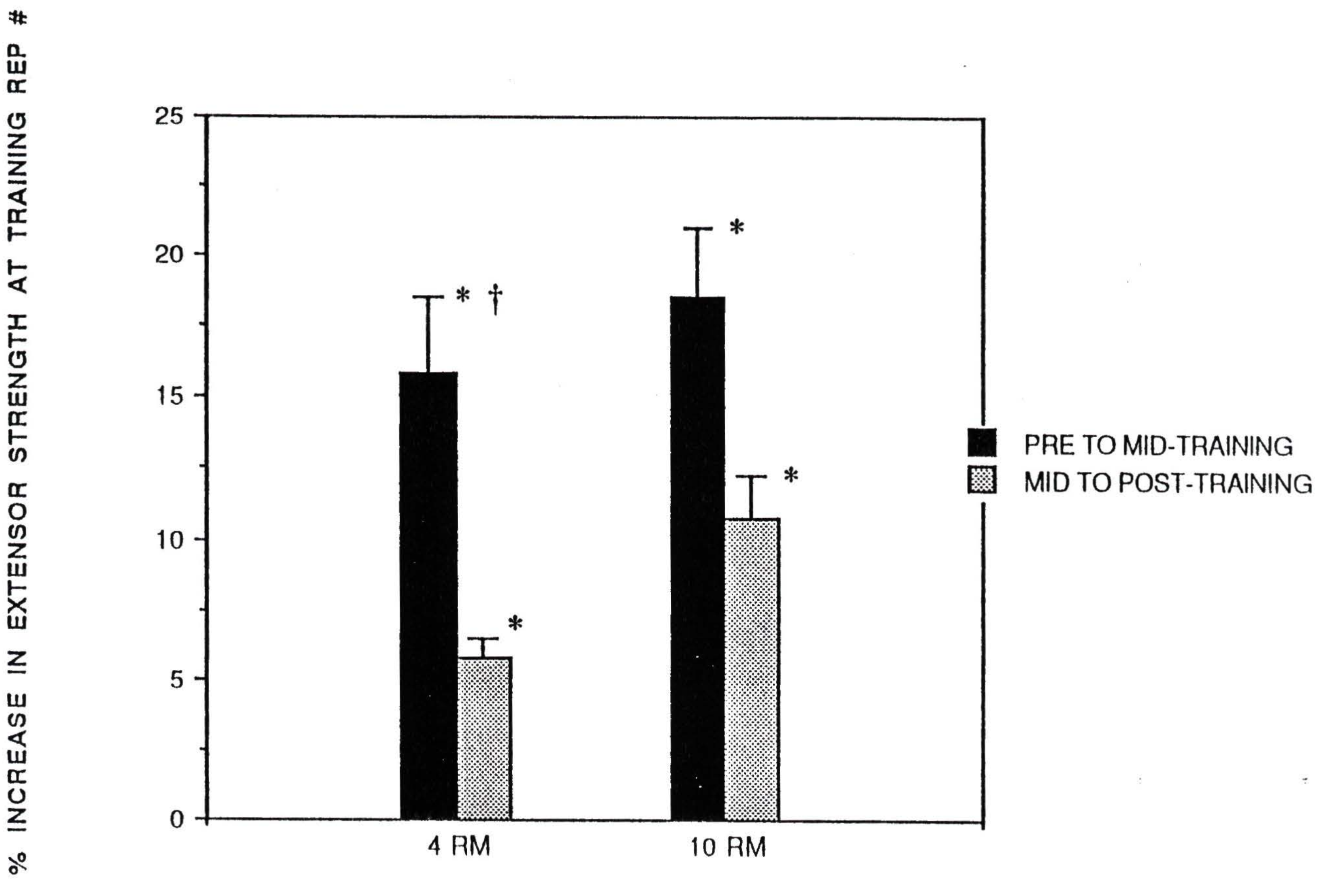
Table 3:

Mean (SE) pre-training to mid-training and mid-training to post-training % increases for forearm extensor and flexor strength at training repetition # of 4 RM (4 reps)[N = 10], and 10 RM (10 reps) [N = 9] groups.

Group	**% Change Tricep (kg)**	**% Change Bicep (kg)**
4 RM (4 reps)		
pre-mid	†*15.9 (2.7)	†*15.0 (3.1)
mid-post	*5.8 (0.7)	*5.7 (1.4)
10 RM (10 reps)		
pre-mid	*18.5 (2.5)	†*16.8 (2.4)
mid-post	*10.8 (1.5)	*8.1 (1.5)

Note: * represents significant within group difference ($p < 0.05$). † represents a significant difference between pre-mid and mid-post values.

Figure 8. Mean (SE) pre-training to mid-training and mid-training to post-training % increases for forearm extensor strength at training repetition # of 4 RM (4 reps) [N = 10], and 10 RM (10 reps) [N = 9] groups. * represents significant within group difference ($p < 0.05$). † represents a significant difference between pre-mid and mid-post values.


% INCREASE IN EXTENSOR STRENGTH AT TRAINING REP #
25
20
15
10
5
0
4 RM
10 RM
*
†
PRE TO MID-TRAINING
MID TO POST-TRAINING

GROUP

Figure 9. Mean (SE) pre-training to mid-training and mid-training to post-training % increases for forearm flexor strength at training repetition # of 4 RM (4 reps) [N = 10], and 10 RM (10 reps) [N = 9] groups. * represents significant within group difference ($p < 0.05$). † represents a significant difference between pre-mid and mid-post values.

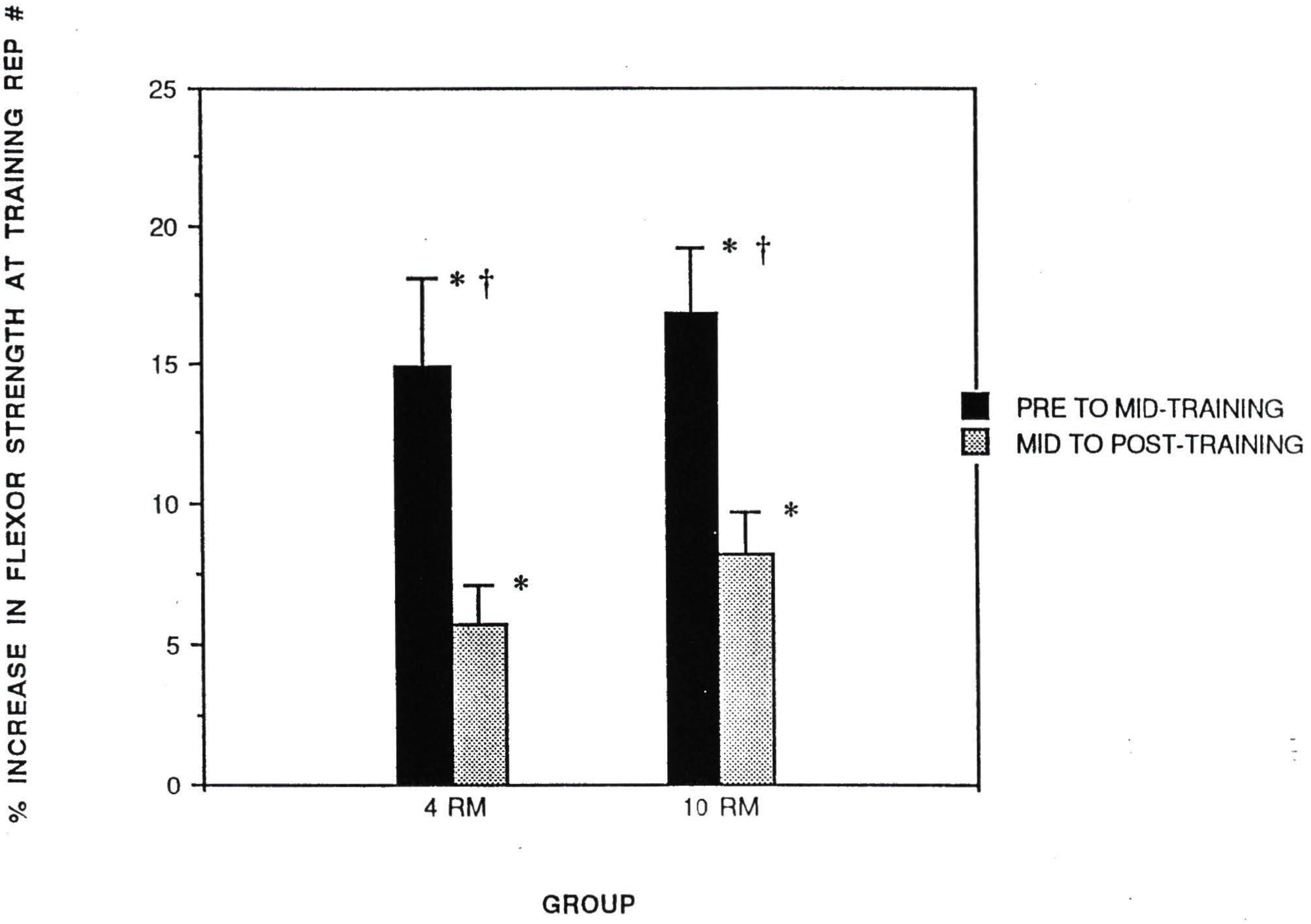

% INCREASE IN FLEXOR STRENGTH AT TRAINING REP #
25
20
15
10
5
0
* †
* †
*
*
4 RM
10 RM
GROUP
PRE TO MID-TRAINING
MID TO POST-TRAINING

Table 4:

Mean (SE) pre-training and post-training midpoint and distal specific tension values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups.

Group	Midpoint (kg/cm^2)	Distal (kg/cm^2)
Control		
pre	2.3 (0.12)	2.5 (0.10)
post	2.4 (0.13)	2.5 (0.10)
4 RM		
pre	2.5 (0.07)	2.6 (0.05)
post	*2.7 (0.04)	*2.8 (0.06)
10 RM		
pre	2.3 (0.13)	2.4 (0.10)
post	*2.5 (0.09)	*2.6 (0.08)

Note: * represents significant difference between pre-training and post-training values ($p< 0.05$).

Figure 10. Mean (SE) pre-training and post-training midpoint specific tension values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups. * represents significant difference between pre and post-training values ($p < 0.05$).

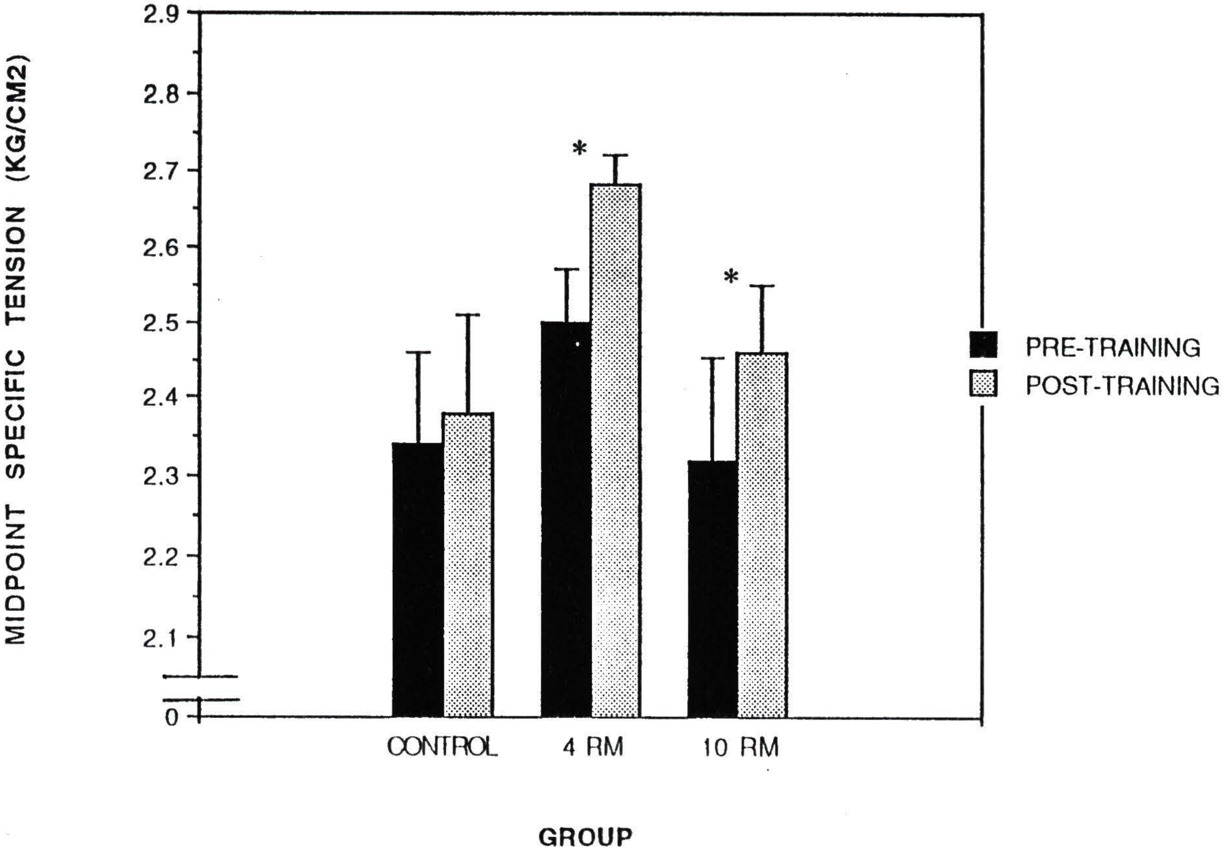

MIDPOINT SPECIFIC TENSION (KG/CM2)
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
0
*
*
CONTROL
4 RM
10 RM
GROUP
PRE-TRAINING
POST-TRAINING

Figure11. Mean (SE) pre-training and post-training distal specific tension values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups. * represents significant difference between pre-training and post-training values ($p < 0.05$).

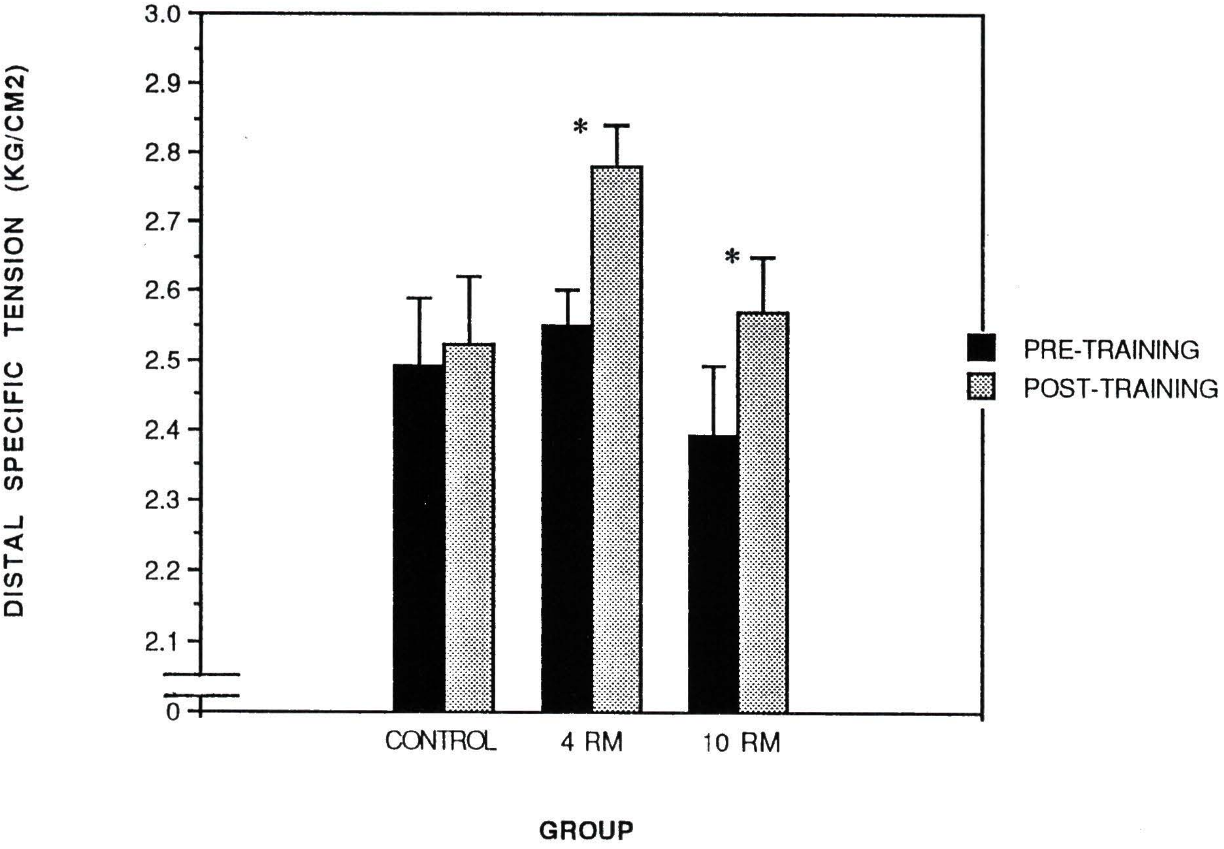

DISTAL SPECIFIC TENSION (KG/CM2)
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
0
*
*
CONTROL
4 RM
10 RM
GROUP
PRE-TRAINING
POST-TRAINING

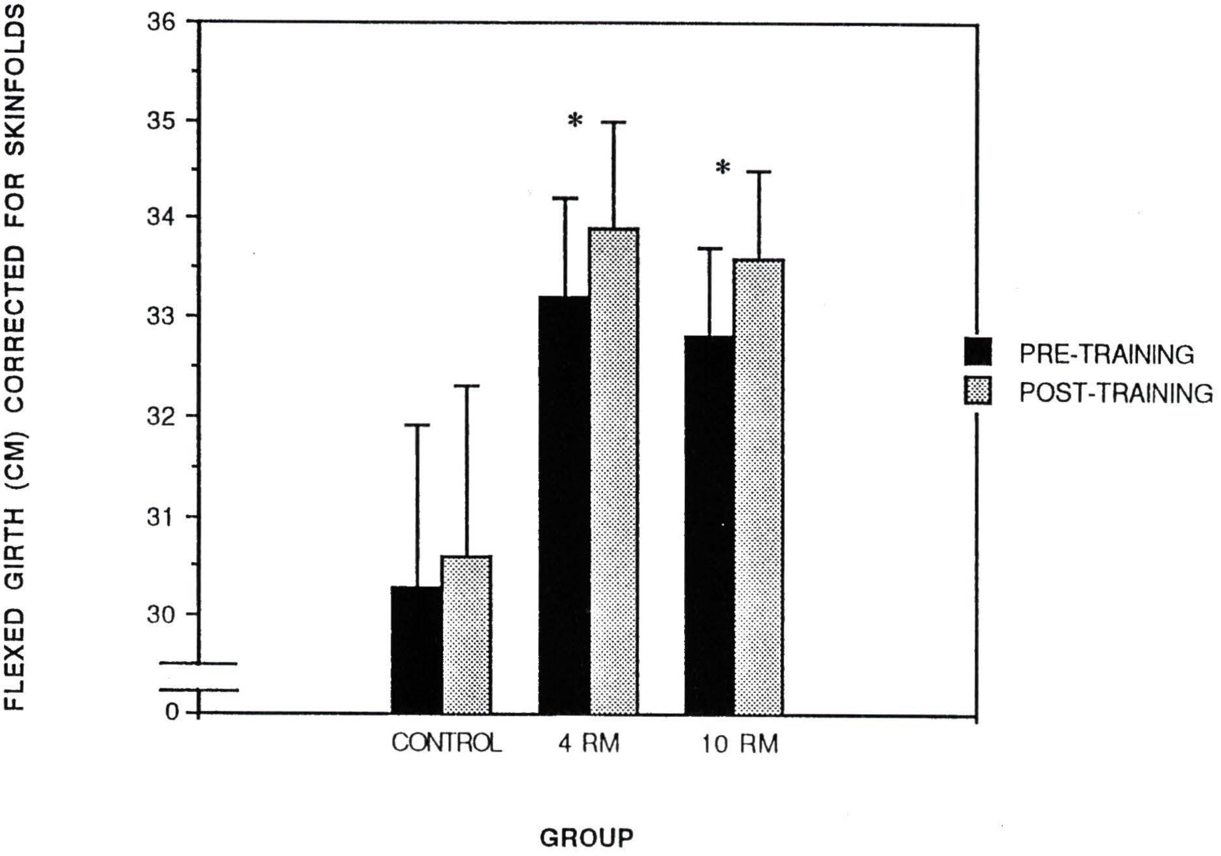
Table 5:

Mean (SE) pre-training and post-training relaxed girth, flexed girth, and sum of skinfolds (SOS) values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups.

Group	Relaxed Girth (cm)	Flexed Girth (cm)	SOS (cm)
Control			
pre	28.5 (1.9)	30.3 (1.6)	1.3 (0.3)
post	28.5 (2.1)	30.6 (1.7)	1.3 (0.3)
4 RM			
pre	31.2 (0.9)	33.2 (1.0)	1.4 (0.1)
post	31.5 (1.0)	*33.9 (1.1)	1.3 (0.2)
10 RM			
pre	31.1 (1.0)	32.8 (0.9)	1.3 (0.2)
post	31.8 (0.9)	*33.6 (0.9)	1.3 (0.2)

Note: * represents significant difference between pre-training and post-training values ($p < 0.05$).

Figure 12. Mean (SE) pre-training and post-training flexed girth (corrected for skinfolds) values of control (N = 5), 4 RM (N = 10), and 10 RM (N = 9) groups. * represents significant difference between pre-training and post-training values ($p < 0.05$).


FLEXED GIRTH (CM) CORRECTED FOR SKINFOLDS
36
35
34
33
32
31
30
0
*
*
PRE-TRAINING
POST-TRAINING
CONTROL
4 RM
10 RM
GROUP

DISCUSSION

Muscle Cross-Sectional Area (CSA)

There have been a wide variety of loading intensities which have been reported to elicit significant increases in muscle fibre or whole muscle CSA (Gonyea & Sale, 1982; MacDougall, Elder, Sale, Moroz, & Sutton, 1980; Narici et al., 1989). Staron, Malicky, Leonardi, Falkel, Hagerman, and Dudley (1989) reported significant increases in CSA using a loading intensity of 6-8 RM. Similar findings were also reported by Sale, Martin, and Moroz (1992) but they utilized much lower loading intensities. Their subjects trained 3 times per week for 19 weeks. In the first session of each week the first work set was done at 15-20 RM, the second work set at 10-15 RM, and the third work set at 7-10 RM. In the second session all three work sets were done at 15-20 RM. In the third session the first work set was at 15-20 RM, and the last two work sets were at 10-15 RM. As only one work set per week was performed in the 7-10 RM range, this illustrates that loading intensities as high as 15-20 RM can increase muscle CSA significantly. Loading intensities equal to or greater than 20 RM have elicited significant increases in muscle fibre or whole muscle CSA in previously untrained individuals (Garfinkel & Cafarelli, 1992; Kraemer et al., 1988; MacDougall, Elder, Sale, Moroz, & Sutton, 1980; McDonagh & Davies, 1984; Narici et al., 1989; Sale, MacDougall, Alway, & Sutton, 1985; Sale et al., 1992).

In the present study both the 4 RM and 10 RM training protocols elicited significant increases in muscle CSA. These results are in agreement with others reported in the literature. Sale, MacDougall, Alway, and Sutton (1985) reported significant increases in muscle CSA with a 3 RM training protocol. 10 RM training protocols have also been reported to increase muscle CSA. Sale et al. (1985), Garfinkel & Cafarelli (1992), and Narici et al. (1989) all reported significant increases in muscle CSA after 10 RM training.

Although there have been many studies investigating the hypertrophic effects of resistance exercise (Garfinkel & Cafarelli, 1992; Gonyea & Sale, 1982; MacDougall et al., 1980; Narici et al., 1989), few have been specifically designed to identify an optimal loading intensity for increasing muscle CSA. As previously mentioned, loading intensities equal to or greater than 20 RM have consistently elicited significant increases in muscle CSA. Nevertheless, some scientists and many practitioners give a guideline of 8-12 RM as the optimal loading intensity for maximizing the hypertrophic response to resistance training (Poliquin, 1988; Poliquin, 1990; Poliquin, 1991; Schmidtbleicher, 1985; Stone, O'Bryant, & Garhammer, 1981).

The 4 RM and 10 RM training regimens used in this study produced similar changes in muscle CSA. Sale et al. (1985) compared 1-3 RM and 10-12 RM loading intensities and, although they did not equate training volumes for the two groups, the results were similar. Sale et al. (1985) reported no difference in CSA adaptations between the 1-3 RM and 10-12 RM training protocols.

Comparing the fibre areas of elite power lifters and body builders has been used to demonstrate the effects of different loading intensities (Kraemer et al., 1988). Power lifters have been reported to have greater mean fibre areas than bodybuilders which has been attributed to the use of relatively higher training intensities and relatively lower training volumes compared to bodybuilders (Tesch, 1992; Tesch & Larsson, 1982). Although this appears to contradict the results of the present study there are some possible explanations. The percentage of fast twitch fibres in the power lifters examined by Tesch

& Larsson (1982) was much higher than that in the bodybuilders (69% FT vs 50% FT). Fast twitch fibres are larger than slow twitch fibres so a significantly larger percentage of fast twitch fibres would result in a larger mean fibre area (Billeter & Hoppeler, 1992). In addition, power lifters and bodybuilders often use the same loading intensities in their training schedules. Power lifters frequently include phases of lower intensity in their periodized training schedules which are similar to those used by bodybuilders and, similarly, bodybuilders include phases of training intensity similar to power lifters (Poliquin, 1988; Poliquin, 1991; Schmidtbleicher, 1985). Furthermore, these results are from highly trained elite power lifters and bodybuilders. It has been established that the response to training in untrained and trained subjects is significantly different (Hakkinen, Komi, Alen, & Kauhanen, 1987). Untrained individuals can demonstrate twice the degree of improvement in half the amount of time and are more likely to respond generically to different types of resistance training intervention (Hakkinen, et al., 1987). In addition, the adaptations elicited by a specific loading intensity in the presence of steroids, not uncommon in elite power lifters and bodybuilders, could be significantly different from those which occur in the absence of these drugs (Tesch, 1992).

Strength

There have also been a wide range of training intensites reported to elicit significant increases in strength in untrained subjects (Kraemer et al., 1988; McDonagh & Davies, 1984). Training protocols utilizing loading intensities as low as 150 RM and as high as 1-3 RM have elicited significant increases in muscle strength (Anderson & Kearney, 1982; Sale et al., 1985). In this study both the 4 RM and 10 RM loading intensities elicited significant strength increases; these results are in agreement with others found in the literature. Both 4 RM and 10RM loading intensities have been reported to significantly increase strength (Berger, 1962; Berger, 1963; Dudley, Tesch, Miller, & Buchanan, 1991; Garfinkel & Cafarelli, 1992; Narici et al., 1989; Sale, 1985; Schmidtbleicher & Haralambie, 1981).

It has been established that significantly different loading intensities can elicit increases in muscle strength (Anderson & Kearney, 1982). It has also been established that "strength" loading intensities are superior to "endurance" loading intensities for eliciting increases in strength (Anderson & Kearney, 1982). However, whether or not different "strength" loading intensities elicit significantly different improvements in strength is not clear. Although the literature is equivocal, there are those who recommend an optimal loading intensity of 1-4 RM for maximizing increases in strength without a concomitant increase in muscle CSA (Baker, 1993; Garhammer & Tokano, 1992; Poliquin, 1988; Poliquin, 1990; Poliquin, 1991; Schmidtbleicher, 1985; Stone et al., 1981).

The magnitude of the increase in strength of the 4 RM and 10 RM training groups in the present experiment did not differ; this is similar to findings of Berger (1963), Schmidtbleicher and Haralambie (1981), and Sale et al. (1985). Berger reported no significant difference in 1 RM strength changes between groups performing 6 sets at 2 RM, 3 sets at 6 RM, and 3 sets at 10 RM (Berger, 1963). Schmidtbleicher & Haralambie (1981) compared a training intensity of 90-100% of maximum voluntary strength (MVS) to one of 30% of MVS. There was no significant difference between the amount of increase in MVS each training intensity elicited. Sale et al. (1985) compared 1-3 RM and 10-12 RM loading intensities; they found no difference between the two loading intensities.

Dudley et al. (1991) compared increases in 3 RM strength among different training protocols and reported a significant difference in strength gains based on increased training intensity. However, the training intensities were actually the same for each group. The difference between the groups was based on the type of muscle actions utilized during training not training intensity. Subjects either performed concentric actions or both concentric and eccentric actions but training intensities remained equal. In addition, the difference between the two groups disappeared when testing was conducted with the same type of muscle actions utilized during training. The group using both eccentric and concentric actions had greater strength gains only when eccentric actions were included in the testing protocol. This suggests that specificity rather than intensity was the variable responsible for the difference in strength gains.

Hakkinen et al. (1987) tested elite powerlifters during a one year training period and reported that increasing loading intensity increased neural drive and strength and that decreasing loading intensity caused a decrease in neural drive and strength. These results do not contradict those found in this experiment. Two different loading intensities were not compared by Hakkinen et al. (1987) because individual athletes periodized their training by changing the intensity throughout the year. Initial strength and neural drive levels were decreased during a training period of decreased intensity and then increased after a subsequent period of increased intensity. Also, highly trained subjects do not respond to training in the same way as untrained subjects (Hakkinen, 1985). Hakkinen et al. (1987) used highly trained elite powerlifters whereas this experiment utilized untrained subjects. The results reported by Hakkinen et al. suggest that loading intensity is a critical factor in maintaining and/or eliciting strength and neural drive gains in highly trained individuals and, in conjunction with the results of the present study, further illustrate the differences in response to training between trained and untrained individuals.

Stone et al. (1981) compared two high intensity training programs and reported that increasing the intensity from 10 RM to 2 RM significantly increased strength gains in untrained subjects. Again, the training protocols utilized by the two groups suggests variables other than intensity could be responsible for the differences in strength gains. Both groups trained three times per week but one group performed 3 sets at 6 RM for the entire duration of the study whereas the other group performed 5 sets at 10 RM for the first 3 weeks, 5 sets at 5 RM for the 4th week, 3 sets at 3 RM for the 5th week, and 3 sets at 2 RM for the final week. The volume of training differed between the groups and the second group had the added stimulus of varying training intensities. Adaptation to training stresses can rapidly deteriorate within only two weeks of exposure to a constant load and, furthermore, adding variety can optimize the training response (Garhammer & Takano, 1992; Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1987; Poliquin, 1988). Varying the training stimulus for one group and not the other could have caused the difference in strength gains.

The fact that adaptation to training stresses can rapidly deteriorate with exposure to a constant loading intensity may also be partially responsible for the differences in pre to mid-training and mid to post-training forearm extensor and flexor % strength increases at training repetition number (4 and 10 in 4 RM and 10 RM groups, respectively) found in this study. Although significant % strength increases occurred between both pre to mid-training and mid to post-training measurements, a significantly greater % increase took place during the pre to mid-training period in both forearm extensor and flexor strength in the 4 RM group (4 reps) and for flexor strength in the 10 RM group (10 reps). The fact that these significant differences only emerged when strength was measured at the same repetition number utilized during training suggests that strength increases may be most specific when related to the number of repetitions utilized during training. However, this pattern of specificity may also be partially attributable to the fact that the increases in strength at training repetition number were calculated as percent increases. As the absolute values for strength were significantly larger at mid-training, the % increases from mid to post-training would be smaller per kg of absolute strength increase.

The pattern of greater strength increases in the first six weeks of the study was also present in both 10 RM and 4 RM groups for forearm extensor and flexor strength measured at 1 RM although the differences were not significant at the $p<0.05$ level. This time course of strength gains has also been attributed to the fact that, in previously untrained muscle, initial strength gains are primarily the result of neural adaptations whereas after approximately six weeks, muscle hypertrophy gradually contributes more to increases in strength (Moritani & DeVries, 1979; Narici et al., 1989). Neural adaptations can occur very rapidly and significant increases in strength can be seen after only one or two training sessions (Moritani & DeVries, 1979; Narici et al., 1989). As hypertrophic adaptations begin to become primarily responsible for increases in strength, the rate of strength increase decreases (Moritani & DeVries, 1979).

Specific Tension

Increases in integrated electromyograph (iEMG) activity in response to training have been interpreted as indications of increases in strength attributable to neural adaptations (Behm & Sale, 1993; Hakkinen & Komi, 1983; Hakkinen et al., 1987; Moritani & DeVries, 1979). An increase in integrated EMG activity is indicative of increased neural activity or an increase in neural drive (Sale, 1992). It has also been reported that resistance training elicits increases in specific tension (Hakkinen & Keskinen, 1989; McDonagh & Davies, 1984; Narici et al., 1989). An increase in specific tension indicates an increase in the force generating capacity of muscle per unit of area and has also been interpreted as evidence of neural adaptation or an increase in neural drive (Garfinkel & Cafarelli, 1992; Hakkinen & Keskinen, 1989; Narici et al., 1989). In the present study both the 4 RM and 10 RM training intensities elicited significant increases in specific tension. There was no difference between the 4 RM and 10 RM training intensities in regard to increases in specific tension. These results suggest that both 4 RM and 10 RM loading intensities evoked equal increases in neural drive.

However, Garfinkell & Cafarelli (1992) found that a 10 RM loading intensity did not significantly increase specific tension in previously untrained subjects. The type of statistical analysis performed on the specific tension data may explain this discrepancy. Garfinkell & Cafarelli (1992) only reported between group data analyses. This did not take into consideration within group differences between pre-training and post-training specific tension. The table of specific tension results showed that there was an increase in specific tension from pre-training to post-training. Paired t-tests may have shown a within-group difference.

Flexed Girth

Significant and equal increases in flexed girth were elicited by both 4 RM and 10 RM training intensities in this study. These results are supported by Moritani & DeVries (1979) who utilized a 10 RM training intensity for forearm flexors and MacDougall, Ward, Sale, & Sutton (1977) who also reported significant increases in girth using an 8-10 RM loading intensity for forearm extensors. These results suggest that simple uncorrected flexed girth measurement could be utilized by practitioners for estimating training-induced CSA changes.

CONCLUSIONS

Both 4 RM and 10 RM loading intensities evoked significant increases in forearm flexor and extensor CSA, flexed girth, and specific tension. Both loading intensities also elicited significant increases in forearm flexor and extensor 1 RM strength and strength at training repetition number (4 and 10 in 4 RM and 10 RM groups, respectively). There was no difference between the 4 RM and 10 RM loading intensities in regard to the magnitude of the adaptations elicited. Both 4 RM and 10 RM loading intensities evoked significant and equal increases in forearm flexor and extensor muscle CSA, strength, specific tension, and flexed girth in previously untrained subjects. It was therefore concluded that in previously untrained males 4 RM and 10 RM loading intensities elicit significant and equal increases in muscle CSA, strength, specific tension, and flexed girth.

Directions for Future Research

Although this study has answered some relevant questions there are many more which require further study. Future research should investigate the specificity of neuromuscular adaptations relative to loading intensities in "trained" subjects. There is some evidence to suggest that in trained subjects loading intensity becomes critical in respect to eliciting neuromuscular adaptations (Hakkinen, 1985; Hakkinen et al., 1987). Trained subjects do respond differently than untrained subjects but the specific physiological factors that are responsible for these differences have not been well researched. At what point does training status begin to affect the neuromuscular response to training? Are there differences between high intensity and low intensity training protocols with respect to CSA changes as well as strength and neural drive changes? Is volume more critical than intensity for evoking CSA changes? Is it necessary to do sets to failure to elicit optimal CSA adaptations? Is intensity critical for evoking strength changes or the principles of specificity and overload? There are many important questions regarding the specificity of neuromuscular adaptations relative to loading intensity which remain unanswered. As untrained subjects seem to respond generically to different loading intensities, future research in this area should involve trained subjects.

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APPENDIX A

Informed Consent

The Effects of 4 RM and 10 RM Weight Training Protocols on Strength, Cross-sectional Area, and Specific Tension in Untrained Males.

This research project is designed to identify the hypertrophic, specific tension, and strength performance effects of typical relative and absolute strength training programs and to determine if the identified hypertrophic, specific tension, and strength performance effects of these programs are significantly different.

Training Procedures

The total duration of the study will be 11 weeks with the first week consisting of an orientation to training protocol. During the orientation each subject will be instructed on proper weight training technique. At the end of the protocol orientation period, subjects will be randomly assigned to either the high loading intensity group (4 RM) or the medium loading intensity group (10 RM). Each training group will contain 12 subjects and the control group will contain 5 subjects. Over the next 10 weeks both groups will train 3 times a week. The 4 RM group will perform 6 sets of each exercise and will perform 4 repetitions per set to failure. The 10 RM group will perform 3 sets of each exercise and will perform 10 repetitions per set to failure. Between each set there will be either a 3 minute rest period (4 RM group) or a two minute rest period (10 RM group) and there will be a minimum of 48 hours of rest between workouts. Throughout the 10 week training period the loads will be monitored to ensure optimal loading intensity. Both groups will perform the following exercises: tricep bench press, tricep pulley press-downs, standing bicep curls, simultaneous dumbell curls, bench press, bench pulls, and shoulder press.

Methods of Data Collection

Data collection will occur at week 0, week 6, and week 10. Strength data will be collected using a free weight tricep press and a free weight barbell curl to determine one repetition and training repetition maximum values. Muscle cross-sectional area data will be collected with magnetic resonance imaging (MRI). Magnetic resonance imagery uses a magnetic field to take a picture of soft tissue. This procedure causes no pain, does not expose the subject to any ionizing radiation, and will be conducted by lab technicians who are highly trained. Anthropometric data will be collected according to protocols outlined in the Canadian Standardized Test of Fitness Operations Manual (1986).

INFORMED CONSENT FOR THE RESEARCH PROJECT:

THE EFFECTS OF 4 RM AND 10 RM WEIGHT TRAINING PROTOCOLS ON STRENGTH, CROSS-SECTIONAL AREA, AND SPECIFIC TENSION IN UNTRAINED MALES

I acknowledge that the research procedures described on the attached form, of which I have a copy, have been explained to me to my satisfaction. I am aware that muscular strength will be measured through determination of 1RM and that muscle cross-sectional area will be measured using the MRI procedure outlined on the attached form. I am also aware that I am entitled to, and may expect, a thorough explanation and/or demonstration of any of the research procedures and that I can terminate my participation in any or all of the procedures at any time. I have been guaranteed anonymity as a participant and assured that all data will be confidential. I agree to participate in this research project with the understanding that my participation or non-participation has no effect upon my grades or standing and I acknowledge that no coercion of any kind has been used.

Having voluntarily consented to participate in this project, I hereby release the University of Victoria and the Greater Victoria Hospital Society, their physicians, agents, servants and employees, and all personnel involved in this research project, from any and all liability for any injury which may result from my participation as a subject in this study.

NAME: ______________________________ PHONE: ________________

SIGNATURE: __________________________ DATE: _________________

WITNESS: ____________________________

APPENDIX B

Review of Literature

INTRODUCTION

Knowledge of the physiological mechanisms associated with resistance training is critical to those designing training programs. Athletes, coaches, trainers, and therapists require knowledge of the neuromuscular adaptations to resistance training in order to design appropriate and successful exercise training programs.

Resistance training with heavy loads increases the force generating ability of skeletal muscle (Behm & Sale, 1993; Enoka, 1988; Hakkinen & Komi, 1983; Jackson, Ratzin, & Ringel, 1990). The ability of skeletal muscle to generate voluntary force is dependent upon the actions of the neuromuscular system. Improvements in the ability to generate force are the consequence of adaptations which have occurred in the neuromuscular system. These adaptations could, theoretically, be either muscular, neural, or a combination of both.

This paper will review the literature related to the neuromuscular adaptations which have the potential to increase voluntary force generation.

MUSCULAR ADAPTATIONS

Muscle Structure and Function

Before discussing the muscular adaptations to resistance training a description of the basic structure and function of muscle and how these relate to force generation will be provided.

Muscle is composed of cellular units called fibres which are made up of rod-like structures called myofibrils (Goldspink, 1992). The myofibrils are arranged in units called sarcomeres with each sarcomere consisting of thick (myosin) filaments surrounded by thin (actin) filaments (Edman, 1992). Each myosin filament is surrounded by six actin filaments in a hexagonal array (Edman, 1992).

Tension or force is generated by a muscle fibre when projections from a myosin filament called crossbridges attach to its corresponding actin filaments. The actin filaments are pulled in over the myosin filament so that each sarcomere shortens (Goldspink, 1992). This happens all along the length of the myofibrils resulting in the muscle as a whole shortening (Goldspink, 1992). Each myosin cross-bridge is an independent force generator so force generation is directly related to the number of myosin crossbridges in parallel interacting with actin filaments (Goldspink, 1992). An increase in the number or size of myofibrils within a muscle fibre indicates a concomitant increase in the number of actin and myosin filaments. This, in turn, is indicative of an increase in the number of myosin crossbridges and therefore increased potential for force generation (Billeter & Hoppeler, 1992).

Muscle CSA and Force Generation

As mentioned above, an increase in the number of cross-bridges increases the force generating ability of the muscle fibre which then increases the force generating ability of the muscle as a whole. For this reason force generation is related to muscle fibre CSA as this is a reflection of myofibrillar content and therefore cross-bridge number. Force generation is also related to whole muscle CSA as this, in turn, is a reflection of muscle fibre CSA. A significant positive relationship between muscle CSA and strength has been established (Billeter & Hoppeller, 1992; Maughan, Watson, & Weir, 1983).

As force generation is related to muscle fibre and whole muscle CSA, increasing the CSA of a muscle fibre or whole muscle, due to increased contractile proteins, would result in an increase in force generating potential. Theoretically, an increase in muscle CSA could be the result of an increase in individual fibre size or CSA (hypertrophy), an increase in fibre number (hyperplasia), and/or an increase in non-contractile interstitial connective tissue.

Hypertrophy

Hypertrophy is defined as an increase in the size of an individual cell or organ (Fox, Bowers & Foss, 1988). The fact that both individual muscle fibre hypertrophy (Dons, Bollerup, Bonde-Petersen, & Hancke, 1979), and increases in whole muscle CSA (Garfinkel & Caferelli, 1992), occur in response to functional overload has been established. This increase in fibre CSA, and therefore muscle CSA, is associated with a large increase or accumulation of myofibrillar protein (Goldspink, 1971). In response to overload, actin and myosin filaments are added to the periphery of existing myofibrils resulting in an increase in individual myofibril area (MacDougall, 1986). This increase in myofibrillar mass volume results in a mismatch between the actin and myosin lattices (Goldspink, 1971). The resulting mismatch causes mechanical stress to occur in the centre of each Z disc which splits the myofibril longitudinally resulting in two daughter myofibrils (Goldspink, 1971). The subdivision of the myofibrillar mass with splitting allows the sarcoplasmic reticulum and transverse tubular systems to invade the mass thus preserving the time related contractile properties (Alway, MacDougall & Sale, 1989).

The exact mechanisms which regulate the hypertrophic response are not known. Hoffman (1980) suggests that skeletal muscle hypertrophy is brought about by a combination of neural and biochemical factors. Hoffman (1980) hypothesized that the neurogenic factor may involve the motoneurone releasing a growth stimulating substance and that the myogenic factor may be linked to the increase of metabolism caused by the influx of calcium ions during depolarization of the muscle membrane. It is believed that the regulation of growth is probably limited by the rate of translation of the message into protein (Goldspink, 1992). Both transcription and translation of myofibrillar proteins increase after exercise induced muscle damage (Russell, Dix, Haller, Jacobs-el, 1992) Ribosomal density increases rapidly and significantly during hypertrophy allowing for the translation of whatever message or messages are involved (Goldspink, 1992). This rapid synthesis of more ribosomes is hypothesized to be the first step in producing muscle fibre hypertrophy (Goldspink, 1992).

The increase or accumulation of proteins in response to functional overload differs between type I fibres and type II fibres. In type II fibres the rate of protein synthesis is increased whereas in type I fibres the rate of protein degradation is decreased (Reichsman, Scordilis, Clarkson, and Evans, 1991). Furthermore, there is evidence that resistance training causes selective hypertrophy of type IIA fibres. A seven week resistance program caused a significant increase in the type IIA:I and the type IIA:IIB fibre area ratios (Costill, Coyle, Fink, Lesmes, & Witzmann, 1979). A cross-sectional study comparing weight lifters, distance runners, and untrained subjects reported that the largest proportion of muscle fibre type in the weight lifters was type IIA. The weight lifters also displayed a significantly larger type IIA fibre area than both the endurance trained and the untrained subjects (Staron, Hikida, Hagerman, Dudley, & Murray, 1984).

Hyperplasia

Hyperplasia refers to an increase in the number of cells in a tissue or organ (Fox, Bowers, & Foss, 1989). Hyperplasia is accepted as the mechanism primarily responsible for muscle growth until early infancy but whether or not hyperplasia occurs as a result of functional overload in adult muscle is controversial (MacDougall, 1992).
There has been some evidence presented in support of hyperplasia being induced in adult mammalian skeletal muscle but this was in animals which underwent types and intensities of overloading not representative of human resistance training methods (Alway, Winchester, Davis, and Gonyea, 1989; Gonyea, Sale, Gonyea, and Mikesky, 1986). Also, research supporting hyperplasia in animals has been criticized due to methodological errors associated with estimation of fibre number (Gollnick, Timson, Moore, & Reidy, 1981; Larsson & Tesch, 1986).

There has also been some indirect evidence of hyperplasia reported in the literature based on the fact that some bodybuilders possess more muscle fibres than untrained subjects (MacDougall, Sale, Elder, & Sutton, 1982; Tesch & Larsson, 1982). This type of evidence is inconclusive as there is no way of determining if the large fibre numbers reported are a result of training or as a result of genetic predisposition. Other research comparing bodybuilders with untrained subjects has illustrated that, although there is a wide range of fibre numbers between individuals, the average number of fibres is the same for bodybuilders and untrained control subjects (MaDougall, Sale, Alway, & Sutton, 1984). Those individuals with the largest muscles, bodybuilders or control subjects, also tended to have the highest number of fibres. This indicates that the genetic determination of not only fibre type, but also of fibre number affects individual potential for muscular hypertrophy. There is no direct evidence from intervention studies illustrating an increase in muscle fibre number in human muscle as a result of training overload.

Connective Tissue

Connective tissue consists of cells and fibres (collagen, elastin, or reticular) imbedded in a gelatinous ground substance containing tissue fluids and various metabolites (Stone, 1988). The primary fibre in all connective tissue is collagen which constitutes approximately 30% of total body protein (Stone, 1988).

The volume density of non-contractile tissue within muscle has been estimated to be 13%, approximately half of which is collagen (MacDougall et al., 1984). Although the absolute amount of connective tissue increases in response to resistance training, the proportion of the muscle that this tissue occupies remains quite constant (MacDougall, 1992). The increase of connective tissue is considered to have a minor effect on muscle fibre hypertrophy.

Although an increase in connective tissue may not significantly contribute to muscular hypertrophy, there has been research which suggests that connective tissue can affect force generation. Enoka (1988) reported that an increase in the strength of connective tissue due to resistance training could improve the transmission of force from individual sarcomeres by decreasing the force which dissipates to surrounding tissue.

NEURAL ADAPTATIONS

Motor Unit Structure and Function

Before reviewing the specific mechanisms responsible for neural adaptation the basic structure and function of the motor unit will be described. The motor unit is the fundamental unit of voluntary movement and therefore the site where training induced neural adaptations occur.

The motor unit consists of one alpha motoneurone, its motor axon, and all the muscle fibres it innervates (Gardiner, 1991). The number of muscle fibres which a motor unit innervates can vary from 5 to more than 100 and the number of muscle fibres contained in a muscle can be in the 1000's (Noth, 1992). The muscle fibres in a motor unit are activated or recruited according to the 'all or none' principle which states that if one muscle fibre is activated all the muscle fibres in that motor unit are activated (Noth, 1992). Generally, muscles used in precision tasks have motor units with few muscle fibres whereas muscles used in gross motor tasks have motor units which innervate many muscle fibres (Noth, 1992).

A single motor unit always consists of homogeneous muscle fibres but motor units differ according to the type of muscle fibres which they innervate and the subsequent metabolic, physiolgical, and electrophysiological properties which they possess (Garnett, O'Donovan, Stephens, & Taylor, 1978; Sickles & Oblak, 1984). The three types of muscle fibres, and accordingly the three types of motor unit, are slow twitch oxidative (type I), fast twitch oxidative-glycolytic (type IIA), and fast twitch glycolytic (type IIB) (Fox, Bowers & Foss, 1988). The properties of the motor unit are matched to the specific response it induces in its fibres. The profile of a motor unit parallels the muscle fibres it innervates with respect to enzyme characteristics, fatigability, firing frequency, excitability, axonal diameter, conduction velocity, and, consequently, force generation (Sickles & Oblak, 1984).

Motor units are recruited according to the size principle which states that smaller motor units which produce smaller amounts of force are recruited before larger motor units which produce larger amounts of force (Nardone & Schieppati, 1987). The only reported exceptions to this have occurred during rapid ballistic movements and in movements involving eccentric contractions where high threshold motor units are preferentially recruited (Nardone, Romano, & Schieppati, 1988).

Evidence of Strength Training Induced Neural Adaptations

Evidence of strength training induced neural adaptations comes from electromyograph (EMG) studies which have shown an increase in integrated electromyograph (iEMG) activity in response to strength training (Hakkinen & Komi, 1983; Behm & Sale, 1993). Electromyography is a method of recording and quantifying the electrical activity produced by motor units during voluntary or involuntary movements (Sale, 1992). An increase in iEMG activity is indicative of increased neural activity or neural drive. This activity could either be an increase in the number of motor units firing or an increase in the firing frequency of motor units (Sale, 1992).

Increases in strength which are not accounted for by muscle hypertrophy have also been interpreted as evidence of neural adaptation. Several studies have elicited an increase in strength without an increase in cross-sectional area (Komi, 1986; Sale, Jacobs, MacDougall, & Garner, 1990). It has also been reported that up to 40% of measured increases in strength could not be accounted for by muscle hypertrophy (Moritani & DeVries, 1979; Narici et al., 1989). This indicates that the force generating capability of muscle per unit of area has been increased. The force generating capability of muscle per unit of area has been defined as specific tension. An increase in specific tension is considered evidence of neural adaptation (Garfinkell & Cararelli, 1992; Narici et al., 1989).

Other evidence of strength training induced neural adaptations comes from research involving the bilateral deficit and crossover training effects in untrained contralateral limbs. The bilateral deficit is a phenomenon which causes the force production of simultaneously contracting limbs to be less than the sum of the force of the two limbs when they are contracted independently (Vandervoort, Sale, & Moroz, 1987). Individuals who train bilaterally show a reduction in the bilateral deficit (Enoka, 1988). The crossover effect is illustrated when a single limb is trained and the contralateral limb shows an increase in strength in the absence of an actual training stimulus (Sale, 1988).

Further evidence of neural adaptation is provided by results of a study by Sale and MacDougall (1981) which indicated that muscle cross-sectional area could be increased through training without a significant increase in strength in unfamiliar movement patterns (Sale & MacDougall, 1981).

Increased Number of Motor Units Recruited

Force generation is positively related to the number of motor units recruited for a particular movement. An increase in the number of motor units recruited therefore results in an increase in the amount of force generated (Doherty, Vandervoort, Taylor, & Brown, 1993). Strength training causes a learning effect which allows some individuals to recruit more motor units following a resistance training period than prior to the training intervention (Sale, Upton, McComas, & MacDougall, 1983). This suggests that some untrained individuals are not able to recruit all available motor units. This further suggests that untrained individuals have a reserve of strength which is independent of any hypertrophic factors. These 'reserve' motor units can be recruited through training which causes an increase of strength without a corresponding increase in muscle cross-sectional area. It has been hypothesized that these 'reserve' motor units are the high threshold motor units which are normally only recruited in trained individuals during maximal efforts (Sale, 1992).

Increased Synchronization of Motor Units

As mentioned above, the ability to fire more motor units to accomplish the same movement task will result in an increase in force production. Similarly, the ability to recruit more motor units at any given point in time could also increase force generation (Edgerton, 1976). This synchronization of motor unit firing was significantly increased in subjects who underwent six weeks of strength training resulting in a 20% increase in strength (Milner-Brown, Stein, & Lee, 1975). Strength trained athletes were also found to have a higher level of synchrony of motor units in the first dorsal interosseus muscle than non-trained controls (Edgerton, 1976). It has been suggested that the supraspinal connections from the motor cortex directly to spinal motoneurones may be enhanced as a result of training and that this may be the adaptation responsible for increased synchronization of motor unit firing (Milner-Brown et al., 1975).

Increased Firing Rate of Motor Units

Firing rate or frequency refers to the number of excitations per second that the muscle fibres of a motor unit receive from the motoneurone. This firing can range from 10-60 impulses per second with the higher threshold motor units possessing the higher firing rates (Sale, 1992). Each excitation causes tension to be developed by the motor unit and is referred to as twitch tension. When firing rate increases, overlap of twitches occurs which causes corresponding increments in force output until complete fusion is reached (Noth, 1992).

Increased integrated electromyograph (iEMG) activity after strength training has been interpreted as an illustration of an increase in motor unit firing frequency (Moritani & DeVries, 1979). It is not clear whether or not the firing frequency of individual motor units increases in response to training, whether more, faster firing, motor units (high threshold) are recruited, or if a combination of both of these events occurs.

If the actual firing frequency of motor units increases this would have implications regarding fibre type transformation. If, for instance, a slow twitch motor unit increased its firing frequency to that of a fast twitch-oxidative motor unit, the muscle fibres within that motor unit would also have to change because the type of muscle fibres within a motor unit always match that of the motor unit itself. Evidence suggests that it is the motoneurone which dictates the fibre type of the muscle fibres it innervates. When the fast twitch motoneurones from a cat hindlimb were cross-reinnervated with slow twitch muscle fibres and vice versa, it was the muscle fibres which took on the characteristics of the motoneurones (Foehring, Sypert & Munson, 1987).

Increased Coordination

Most voluntary movements performed by the human body require the contraction of more than one muscle at time. The force produced in such movements is positively related to the sum of the force produced by each muscle involved in the movement. The main muscle group responsible for a movement is called the agonist, the muscle groups which assist in the movement are called synergists, and the muscle groups which act in opposition to the agonists are called antagonists (Buchanan, Rovai, & Rymer, 1989). In order to generate maximum force in movements which include more than one muscle group, the most efficient activation of all the involved muscles, and the motor units they possess would have to occur. This would not only include maximum activation of the agonists and synergists but also inhibition of the antagonist muscles. Being able to recruit the involved musculature in such a manner is termed coordination and is a learned phenomenon (Rutherford & Jones, 1986). Neural adaptation within reflex arcs is thought to be responsible for improving coordination (Hakkinen & Komi, 1986).

Increased Rate of Force Production

Some trained individuals such as ski jumpers are able to achieve peak force more rapidly than untrained individuals which suggests that rate of force development can be increased with training. There is evidence that a neural component is involved in determining rate of force production. Explosive jump training has been shown to cause an increase in the rate of the onset of motor unit activation and therefore force production (Hakkinen, Alen, & Komi, 1985).

Also, research indicates that force production at a given movement velocity is dependent upon the speed of contractions utilized during training. Subjects who train at low velocities see significantly more strength improvements at low velocities than high velocities and vice versa (Hakkinen & Komi, 1986; Sale & MacDougall, 1981). This specificity of velocity of training is thought to be a neural phenomenon. The organization and central command of rapid movements differ from that of slow actions (Sale, 1992). Ballistic movements place unique demands on the neural system and because of this differ from slower movements in several ways. Ballistic movements are initiated differently by the brain, are characterized by a brief high frequency discharge of the involved motor units, may involve selective activation of high threshold motor units, and involve a characteristic pattern of agonist and antagonist discharge (Behm & Sale, 1993).

A trait of movements requiring the most rapid rate of force development is that they are pre-programmed. Once the central command has reached the motoneurones, it cannot be modified on the basis of a new command or proprioceptive feedback (Behm & Sale). This implies that once there has been an intent to make a ballistic movement, the muscle fibres will receive that signal whether or not they are able to perform the movement or not. Behm and Sale (1993) illustrated in a recent study that even if the ankle was restrained during the training sessions, if the subject's intent was to perform a ballistic movement, the training elicited adaptations would be the same as that which would have occured if the ballistic movement had been performed.

Increased Conduction Velocity

Nerve conduction velocity refers to the speed of impulse propogation along the motoneurone. Axonal diameter has the greatest effect on nerve conduction velocity as conduction velocity is directly related to the size of the cell body (Kernell & Zwaagstra, 1981). Compensatory overload of muscles through elimination of synergist function has been shown to cause nerve fibre hypertrophy (Walsh, Burke, Rymer, and Tsairis, 1978) which, due to the direct relationship between axonal diameter and conduction velocity, theoretically should increase conduction velocity. An increase in conduction velocity could potentially increase motor unit firing rate which, in turn, has the potential to increase rate of force development. After periods of immobilization, weight trainers have been reported to have faster nerve conduction velocities than control subjects (Sale et al., 1983).

CONCLUSION

This review of research has illustrated that there are neural and muscular adaptations which occur in response to resistance training with high loads. The muscular adaptations to resistance training consist primarily of a hypertrophic response which causes an increase in the CSA of individual muscle fibres and, potentially, whole muscle CSA. The neural adaptations to resistance training involve an increase in the ability of the nervous system to optimally recruit available muscle mass. These adaptations may include an increase in the number of motor units recruited, an increase in the firing frequency of motor units, an increase in the sychronization of motor unit firing, and/or a decrease in inhibitory mechanisms.

A review of the literature has provided an understanding of the neuromuscular adaptations which occur in response to resistance training. An understanding of these adaptations provides those who design training programs with a fundamental basis with which to develop appropriate resistance training or rehabilitation programs. It is, however, not enough to just identify the adaptations which occur in response to resistance training. Those who design programs need to have information regarding the specificity of these neuromuscular adaptations specific to different resistance training protocols. It is possible that different training protocols could elicit different types and/or degrees of adaptation. This information is critical to those designing programs for individuals with very specific needs. Future research should be directed at providing information regarding the specificity of neuromuscular adaptations specific to different training protocols.

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