EFFECT OF RANGE OF MOTION ON MUSCLE STRENGTH AND THICKNESS

RONEI S. PINTO,[1] NAIARA GOMES,[1] RÉGIS RADAELLI,[1] CÍNTIA E. BOTTON,[1] LEE E. BROWN,[2] AND MARTIM BOTTARO[3]

[1]*College of Physical Education, Exercise Research Laboratory, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil;* [2]*Department of Kinesiology, Human Performance Laboratory, California State University, Fullerton, California; and* [3]*College of Physical Education, Strength Training Laboratory, University of Brasília, Brasília, DF, Brazil*

ABSTRACT

Pinto, RS, Gomes, N, Radaelli, R, Botton, CE, Brown, LE, and Bottaro, M. Effect of range of motion on muscle strength and thickness. *J Strength Cond Res* 26(8): 2140–2145, 2012—The purpose of this investigation was to compare partial range-of-motion vs. full range-of-motion upper-body resistance training on strength and muscle thickness (MT) in young men. Volunteers were randomly assigned to 3 groups: (a) full range of motion (FULL; $n = 15$), (b) partial range of motion (PART; $n = 15$), or (c) control (CON; $n = 10$). The subjects trained 2 d·wk^{-1} for 10 weeks in a periodized program. Primary outcome measures included elbow flexion maximal strength measured by 1 repetition maximum (1RM) and elbow flexors MT measured by ultrasound. The results indicated that elbow flexion 1RM significantly increased ($p < 0.05$) for the FULL (25.7 ± 9.6%) and PART groups (16.0 ± 6.7%) but not for the CON group (1.7 ± 5.5%). Also, FULL 1RM strength was significantly greater than the PART 1RM after the training period. Average elbow flexor MT significantly increased for both training groups (9.65 ± 4.4% for FULL and 7.83 ± 4.9 for PART). These data suggest that muscle strength and MT can be improved with both FULL and PART resistance training, but FULL may lead to greater strength gains.

KEY WORDS full range of motion, partial range of motion, 1 repetition maximum, ultrasonography, strength training

INTRODUCTION

Resistance training has been shown to be an effective stimulus for increasing muscle strength and hypertrophy (2). Optimally designed resistance training programs are based on scientific principles that control critical training variables. These variables include exercise order, frequency, volume, intensity, between-set rest intervals, and others (2,3,13). Besides these critical variables, range of motion (ROM) can also be manipulated for strength gains (10,16).

Studies that have investigated the acute effects of performing partial or full ROM strength training have reported that higher loads can be lifted when performing a bench press exercise with partial ROM. Massey et al. (15) suggested that lifting through a full ROM is superior for strength gains when compared with lifting with partial or mixed ROM. Also, resistance exercise is often performed within a specific, restricted joint ROM after orthopedic injury or surgery or when pain and muscle weakness limit ROM (11). In addition, exercises that use full ROM may not provide the optimal stimulus for enhancing sports performance (6).

A great amount of research on the chronic effects of resistance training has been carried out in the area of partial vs. variable ROM resistance exercise (6,7,10,11,15,16). These investigations have focused on the effects of different ROM training and its effectiveness in promoting the development of full and partial ROM strength. However, the results from these previous investigations are still contradictious. Graves et al. (10,11) reported that after dynamic resistance training, angle-specific (partial ROM) effects occurred for limited and full ROM. Likewise, Massey et al. (16) compared partial ROM vs. full ROM training and reported that partial and full ROM positively influenced the development of full ROM maximal bench press strength. In a related study, Massey et al. (15) reported a statistically significant gain in bench press 1 repetition maximum (1RM) strength for a full ROM group when compared with partial and mixed ROM groups. Recently, Clark et al. (7) examined whether variable ROM training was superior to full ROM strength training. They found that variable ROM training significantly increased both full ROM bench throw displacement and half ROM bench throw peak force.

The preponderance of previous research looking at ROM has focused on strength responses without investigating hypertrophic or morphological adaptations. Also, the majority of the chronic studies focus on knee extensors (10), lumbar extensors (11), and horizontal shoulder flexors

Address correspondence to Ronei S. Pinto, ronei.pinto@ufrgs.br.

26(8)/2140–2145

Journal of Strength and Conditioning Research

(6,15,16) muscle strength gains. Therefore, because of controversy between studies relating to strength gains and the lack of chronic studies comparing full and partial ROM on elbow flexors strength gains and muscle hypertrophy, the purpose of this investigation was to compare partial vs. full ROM upper-body resistance training on strength and muscle thickness (MT) in young men.

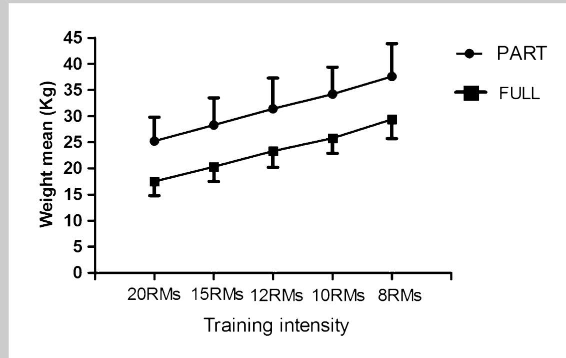

Figure 2. Weight mean used by FULL and PART during the 10 weeks.

Methods

Experimental Approach to the Problem

The subjects were matched according to their maximum elbow flexion strength and assigned to 1 of 3 groups. One group performed full range-of-motion (FULL) elbow flexion exercise, whereas the other performed partial range-of-motion (PART) elbow flexion exercise. The third group was used as a control (CON). Training was conducted 2 $d \cdot wk^{-1}$ for 10 weeks, with a minimum of 48 hours between sessions. Strength and MT were tested before and after the 10-week training protocol via 1RM and ultrasound, respectively.

Subjects

Forty young men with no resistance training experience participated in this study. Fifteen subjects in the FULL group (age = 21.7 ± 3.5 years; body mass = 74.9 ± 11.0 kg; height = 177.0 ± 2.0 cm), 15 in the PART group (age = 21.7 ± 3.3 years; body mass = 73.0 ± 8.9 kg; height = 180.0 ± 3.4 cm), and 10 in the CON group (age = 24.5 ± 2.9 years; body mass = 73.0 ± 5.7 kg; height = 175.0 ± 3.2 cm) completed the study protocol. The inclusion criteria for participation in the study included being older than 18 years and being free of clinical problems that could be aggravated by the protocol. The participants were notified of the research procedures, requirements, benefits, and risks before providing informed consent. The study was approved by the Ethics Committee of Federal University of Rio Grande do Sul, Brazil.

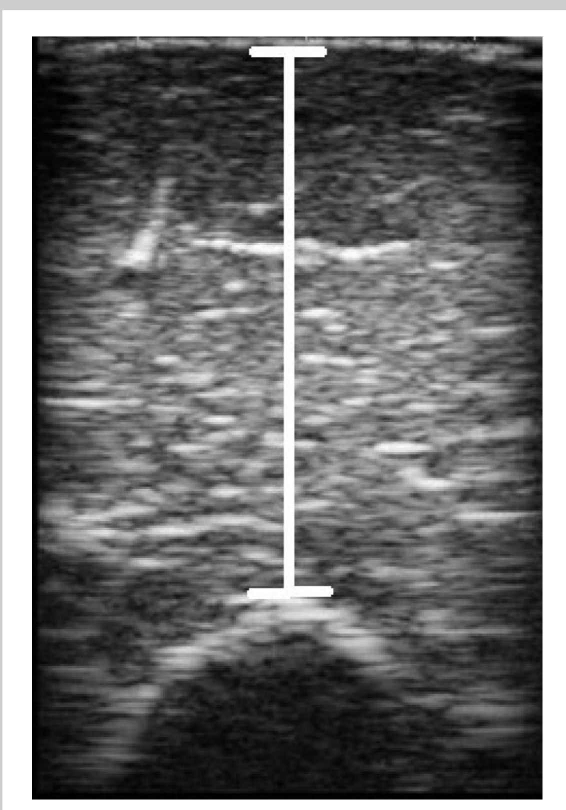

Figure 1. Muscle thickness (MT) of the elbow flexor measurement from ultrasound. Distance from the subcutaneous adipose tissue-muscle interface to the muscle-bone interface.

One-Maximum Repetition Test

To assess the elbow flexion force production from both groups, a 1RM test was performed at full range of motion in

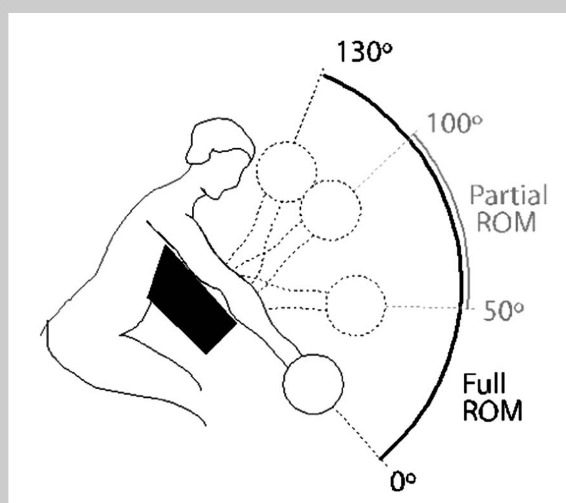

Figure 3. Elbow flexion range of motion (ROM) performed from both training groups (FULL and PARTIAL).

TABLE 1. Results from 1RM tests before and after 10 weeks of training.*†

1RM test	FULL	PART	CON
Baseline (kg)	27.3 ± 3.3	29.7 ± 6.8	27.5 ± 6.8
10 wks (kg)	34.3 ± 5.2	34.4 ± 8.3	27.8 ± 6.2
Δ%	25.7 ± 9.6‡§	16.0 ± 6.7‡	1.7 ± 5.5

*1RM = 1 repetition maximum; FULL = full-range-of-motion group; PART = partial-range-of-motion group; CON = control group.
†Values are given as mean ± *SD.*
‡Higher than baseline ($p < 0.05$).
§Higher than PART ($p < 0.05$).

a bilateral mode preacher curl exercise with the radioulnar joint supinated using a curling bar. During the test, the subjects were seated with both feet on the floor. The height of the preacher curl bench was adjusted for each subject so the trunk was straight, whereas the back of the arm and the axillae were rested on the pad. Three to 5 attempts were made to reach the 1RM with a 5-minute rest interval between each lift. The maximum weight that was successfully lifted was recorded (3). To exclude any learning effect and to measure test-retest reliability, the 1RM test was performed 3 times by each subject during the familiarization process. The tests were performed with a minimum of 72 hours between each testing session. Elbow flexor 1RM baseline test-retest intraclass correlation coefficient (ICC) was 0.91.

Muscle Thickness

The participants were tested before and after the 10-week training period for MT of the elbow flexors of the right limb. All the tests were conducted at the same time of the day, and the participants were instructed to hydrate normally 24 hours before the tests. Measures were taken 3–5 days after the last training session to prevent any swelling from contributing to the MT measurement (5). During this time, the subjects were instructed not to participate in any other exercise sessions or intense activity. The MT was measured using B-Mode ultrasound (Philips-VMI, Ultra Vision Flip, model BF, Lagoa Santa, MG, Brazil). A water-soluble transmission gel was applied to the measurement site, and a 7.5-MHz ultrasound probe was placed perpendicular to the tissue interface without depressing the skin. The MT of the elbow flexors was measured according to the method of Abe et al. (1). Once the technician was satisfied with the quality of the image, it was frozen on the monitor. With the image frozen, a cursor was used to measure the distance from the subcutaneous adipose tissue-muscle interface to the muscle-bone interface (Figure 1). A trained technician performed all analyses (20). Baseline test and retest ICC for elbow flexors MT was 0.96.

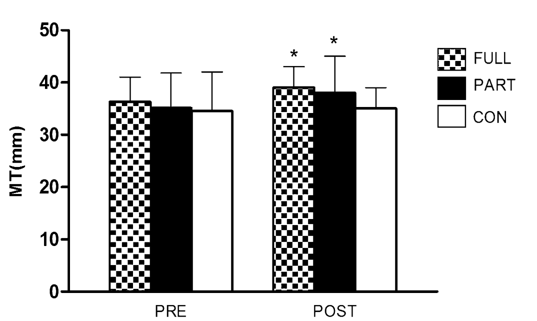

Figure 4. Results from muscle thickness (MT) measurements before and after 10 weeks of training. *Higher than baseline ($p < 0.05$); FULL = full-range-of-motion group; PART = partial-range-of-motion group; CON = control group.

Strength Training

All training sessions were closely supervised to ensure safety and compliance with the procedures and because previous research has demonstrated greater gains in supervised vs. unsupervised training (9). Each subject maintained a training log where the number of repetitions performed and the weight used in each set were recorded. Training was conducted 2 $d{\cdot}wk^{-1}$, for 10 weeks with a minimum of 48 hours between sessions. Twice per week training sessions were chosen because the current physical activity guidelines state that adults should do at least 150 $min{\cdot}wk^{-1}$ of moderate-intensity physical activity and also ≥2 $d{\cdot}wk^{-1}$ of muscle-strengthening activities (18). Periodization was systematically manipulated in a linear model (Figure 2). The number of sets increased from 2 (weeks 1 and 2) to 4 (weeks 9–10), and the number of RM decreased from 20 (weeks 1 and 2) to 8 (weeks 9 and 10). The elbow flexion training was performed in a bilateral mode preacher curl exercise. Both groups (FULL and PART) followed the same routine during the 10 weeks, but the FULL group performed elbow flexion with full (0° to 130° of elbow flexion – 0° full elbow extension) ROM, whereas the PART group performed partial (50° to 100°) ROM (Figure 3). Also, the ROM from the PART group was controlled by 2 metallic bars that limited the barbell displacement during each repetition. If the subjects could not perform the number of repetitions or could lift the load more than stipulated, they were instructed to adjust the load to ensure completion of the required number of repetitions. The subjects were instructed to maintain their normal diet over the duration of the study.

Statistical Analyses

Normality of the distribution for outcome measures was tested using the Kolmogorov-Smirnov test. All the values are reported as mean ± *SD*. The differences in 1RM and MT between groups were compared with a mixed model 2-way ANOVA (group [FULL, PART, and CON] × time [pretest and posttest]) followed by the least significant difference post hoc procedure whenever necessary. Statistical significance was set at $p \leq 0.05$. Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 17 software (SPSS Inc., Chicago, IL, USA). Also, the effect size was calculated for strength and MT gains according to Rhea (19) for resistance training effects.

Results

The results from the 1RM strength tests are presented in Table 1. The pretest 1RM initial scores were the same ($p > 0.05$) regardless of the 3 groups tested (FULL, PARTIAL, CON); however, the 1RM analysis of variance (ANOVA) revealed a significant interaction of group by time. This was followed-up with three 1 × 2 ANOVAs for time for each group and revealed a significant ($p < 0.05$) increase in 1RM for both the FULL and PART groups but not for the CON group ($p = 0.25$). In FULL and PART, 1RM significantly increased 25.7 and 16.0% above baseline values, respectively. The effect size for the changes in strength was moderate to large (1.89) for FULL and small (0.87) for PART.

The pretest MT initial values were the same ($p > 0.05$) regardless of the 3 groups tested (FULL, PARTIAL, CON); however, the MT ANOVA also revealed a significant interaction of group by time. This was followed up with three 1 × 2 ANOVAs for time for each group and revealed a significant ($p < 0.05$) main effect for time for both FULL and PART groups but not for the CON group ($p = 0.36$) (Figure 4). In FULL and PART, MT significantly increased 9.52 and 7.37% from baseline values, respectively. The effect size for the changes in MT was 1.09 for FULL and 0.57 for PART.

Discussion

The purpose of this study was to compare the effects of FULL vs. PART ROM resistance training on strength and MT of the elbow flexors. Although, the training volume from the full ROM group was 36% lower than that of the partial ROM group, the results of this study suggest that, for strength, lifting through a full ROM was superior to that through a partial ROM. Another main finding from our study was that the training volume used was sufficient to improve the MT of the right arm elbow flexors for both training groups but not for the CON group. On the other hand, the MT for full (9.7%) was greater than that for the CON (−2.4%) but not significantly ($p = 0.07$) different from partial ROM (7.8%).

The effects of different resistance training ROM on neuromuscular responses have been the subject of a few acute (6,17) and chronic studies (7,10,11,15,16). The first study investigated the effect of different ROM training on strength gains at specific angles and showed that muscle strength improves more at the joint angles trained and not completing the full ROM may result in weakness at untrained angles (10). On the other hand, the same authors later reported that partial training also improves full ROM strength in the lumbar extensor muscles (10). Other studies have assessed the effects of different ROM training on full ROM strength gains. Massey et al. (16) compared the effects of partial ROM and full ROM training on the development of maximal bench press strength. They divided their male subjects into 3 groups. One group trained with full ROM, another group trained with partial ROM, whereas the last group trained with mixed ROM (partial and full). They found no difference in 1RM bench press strength gains between groups. These results are not in agreement with those of this study in which the full group's strength increased more than the partial group's (25.7 and 16.0%, respectively). Interestingly, another study (15) using female subjects found similar results to those of our study in that bench press strength gains when training through a full ROM (34.8%) were superior to those through a partial ROM (22.5%) and mixed (23.1%) training. They speculated that the differences in results could possibly be because of the relative lack of experience of the women subjects. These results are in agreement with those of this study, which also used naive subjects.

Recently, Clark et al. (7) using 2 groups of athletes with extensive resistance training backgrounds investigated the effects of 5 weeks of mixed ROM training, consisting of partial ROM training performed in a different phase of the ROM for each set, on isokinetic and isometric bench press and ballistic bench throws. They compared these with a control group performing full ROM bench press. Their results revealed that the mixed ROM group significantly improved bench throw displacement (15.5%) under the full ROM testing condition, despite there being no significant increase in peak force during the full ROM countermovement (+1.6%). In contrast, the mixed ROM group produced significantly greater peak force (+15.7%) in the half ROM countermovement throws. Interestingly, they reported a decrease in bench throw displacement (−3.7%), bench throw peak force (−1.8%), and half ROM bench throw peak force (−3.5%) in the full ROM group. Thus, they concluded that mixed ROM training is better than full ROM training to improve an athlete's reactive strength and dynamic force performance at shorter muscle lengths. The results of Clark et al. (8) and Massey et al. (16) are, in part, not in agreement with ours and the Massey et al. (15) findings. The differences may be related to the subjects training status. Massey et al. (16) used recreationally trained subjects, and Clark et al. (7) used well-trained athletes, whereas this study and the Massey et al. (16) study used only naive subjects.

Another explanation may be that, in skeletal muscle fiber, the amount of tension generated during a contraction depends on the number of pivoting crossbridges in the sarcomeres along the myofibrils. The tension produced by the entire muscle fiber can thus be related to the length of an individual sarcomere, which is related to the joint angle. Within the optimal range of sarcomere lengths, the maximum number of crossbridges can form and the tension produced is greatest. Thus, the force produced when resistance training at different ROMs can vary according to the angle trained. This may have impacted our results as one major difference between this study and other studies was that in our study partial ROM subjects trained the elbow flexion exercise through the midrange of ROM (50–100° of elbow flexion − 0° full extension), whereas the full group trained from 0 to 140°. Other studies have trained partial ROM using the initial or end range of the ROM (10,11), mixed variable ROM (8), or beyond the sticking point (2–5 in. from the full extension of the elbow) of the bench press exercise (15,16). Therefore, in this study, the partial group trained through the ROM near of optimal angle of the elbow flexion strength curve (14). Furthermore, in this study, the exercise used was a single-joint exercise (arm curl), whereas the other studies used a multijoint exercise (bench press). This is an important point because during a multijoint movement, different muscles contract through different lengths throughout the full ROM, and they are not all at optimal lengths for force production. Therefore, at any given joint angle, some muscles may produce their maximal force whereas other muscles are less than optimal.

Thus, based on our results and the results of previous studies, it can be suggested that because athletes are often required to perform countermovements at different ROM levels during sport, they may benefit from resistance training programs that use various ROM movements. On the other hand, beginners may benefit from training with full ROM because it can better improve full ROM strength and reduce the risk of sustaining an injury. Previous studies have revealed that both the load lifted and peak force output increase as the ROM of the resistance exercise is decreased (6,17). In this study, the risk of sustaining an injury and developing joint stress was probably reduced in the full ROM group when compared with that in the partial group given that the partial group lifted approximately 36% heavier loads than the full group did. Also, at a constant rate of contraction, limiting the ROM during a resistance exercise session would restrict blood flow and allow an increased number of repetitions to be performed in a given amount of time. Together, these factors may increase cardiovascular, blood lactate, and perceived exertion responses (22).

To our knowledge, this was the first study to assess the effects of different ROM resistance training on MT gains via ultrasound. It is generally accepted that there is a delay before the onset of muscle hypertrophy and that initial strength gains primarily result from the adaptation of neural factors (1). The force that a muscle exerts depends on the amount of motor unit recruitment and the rate at which motor neurons discharge action potentials (rate coding). However, muscle hypertrophy adaptations assessed with imaging techniques such as ultrasound (1,5,23), computerized tomography (8), or magnetic resonance imaging (4,12) have typically been found only after 8–12 weeks of resistance training. Thus, we can suggest that part of the strength gains in both training groups in our study may be because of muscle hypertrophy. Also, it is important to mention that the magnitude of our treatment effect for MT was almost twice as greater for full (1.09) when compared with partial ROM (0.57). This finding is important because the effect size, in the practical point of view, enables this study to suggest that training using full ROM may have a greater impact on MT than training at partial ROM in untrained individuals. Furthermore, we may also hypothesize that the lack of difference in MT between groups could be related to low training duration, training frequency, or sensitivity of the ultrasound measurement system. According to Seynnes et al. (21), it seems likely that the often described delay in onset of muscle hypertrophy observed in previous studies is partly because of the sensitivity of the method used to detect hypertrophy.

In summary, it was concluded that full ROM resistance training protocols are better than partial ROM for increasing full ROM strength of the elbow flexors in untrained individuals. Although the purpose of our study was to compare full vs. partial ROM on the development of full ROM strength, a potential limitation of this study is that the 1RM strength test was not conducted at partial ROM. Previous research reported that training at restricted angle of the training movement does increase strength within that specific ROM (10,11). As a result, we would expect that the partial group in this study would have greater strength gains during the partial 1RM test because of specific angles and also higher training loads lifted. Thus, future investigations should focus on the effects of different ROM training volumes and durations on muscle strength and hypertrophy. Also, it would be important to investigate if different ROM strength training is influenced by the exercise and muscle group used (i.e., single- vs. multijoint).

Practical Applications

The use of a proper ROM in resistance training exercises is essential for strength and muscle mass gains in novice lifters. Thus, it is important that strength coaches and exercise professionals emphasize the use of full ROM execution during strength exercises in the early phase of a strength training program in naive subjects. Furthermore, the use of full ROM may lead to less psychological and bone joint stress, because full ROM uses a lesser load for the same number of repetitions than partial ROM does. However, partial ROM can be used in later stages of training or by athletes. Also, as suggested by Clark et al. (7), training at variable ROM appears to be a beneficial component in an athlete's attempt to achieve optimal sporting performance.

Acknowledgments

The authors wish to confirm that the present experimental methods comply with the current laws of the country in which they were performed. The authors wish to confirm that there is no conflict of interest associated with this publication and that there has been no significant financial support for this work that could have influenced its outcome.

References

1. Abe, T, DeHoyos, DV, Pollock, ML, and Garzarella, L. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *Eur J Appl Physiol* 81: 174–180, 2000.
2. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
3. Baechle, TR, Earle, RW, and National Strength and Conditioning Association (U.S.). Essentials of Strength Training and Conditioning. Champaign, IL: Human Kinetics, 2008.
4. Blazevich, AJ, Cannavan, D, Coleman, DR, and Horne, S. Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. *J Appl Physiol* 103: 1565–1575, 2007.
5. Chilibeck, PD, Stride, D, Farthing, JP, and Burke, DG. Effect of creatine ingestion after exercise on muscle thickness in males and females. *Med Sci Sports Exerc* 36: 1781–1788, 2004.
6. Clark, RA, Bryant, AL, and Humphries, B. An examination of strength and concentric work ratios during variable range of motion training. *J Strength Cond Res* 22: 1716–1719, 2008.
7. Clark, RA, Humphries, B, Hohmann, E, and Bryant, AL. The influence of variable range of motion training on neuromuscular performance and control of external loads. *J Strength Cond Res* 25: 704–711, 2011.
8. Garfinkel, S and Cafarelli, E. Relative changes in maximal force, EMG, and muscle cross-sectional area after isometric training. *Med Sci Sports Exerc* 24: 1220–1227, 1992.
9. Gentil, P and Bottaro, M. Influence of supervision ratio on muscle adaptations to resistance training in nontrained subjects. *J Strength Cond Res* 24: 639–643, 2010.
10. Graves, JE, Pollock, ML, Jones, AE, Colvin, AB, and Leggett, SH. Specificity of limited range of motion variable resistance training. *Med Sci Sports Exerc* 21: 84–89, 1989.
11. Graves, JE, Pollock, ML, Leggett, SH, Carpenter, DM, Fix, CK, and Fulton, MN. Limited range-of-motion lumbar extension strength training. *Med Sci Sports Exerc* 24: 128–133, 1992.
12. Hubal, MJ, Gordish-Dressman, H, Thompson, PD, Price, TB, Hoffman, EP, Angelopoulos, TJ, Gordon, PM, Moyna, NM, Pescatello, LS, Visich, PS, Zoeller, RF, Seip, RL, and Clarkson, PM. Variability in muscle size and strength gain after unilateral resistance training. *Med Sci Sports Exerc* 37: 964–972, 2005.
13. Kraemer, WJ and Ratamess, NA. Fundamentals of resistance training: Progression and exercise prescription. *Med Sci Sports Exerc* 36: 674–688, 2004.
14. Kulig, K, Andrews, JG, and Hay, JG. Human strength curves. *Exerc Sport Sci Rev* 12: 417–466, 1984.
15. Massey, CD, Vincent, J, Maneval, M, and Johnson, JT. Influence of range of motion in resistance training in women: Early phase adaptations. *J Strength Cond Res* 19: 409–411, 2005.
16. Massey, CD, Vincent, J, Maneval, M, Moore, M, and Johnson, JT. An analysis of full range of motion vs. partial range of motion training in the development of strength in untrained men. *J Strength Cond Res* 18: 518–521, 2004.
17. Mookerjee, S and Ratamess, N. Comparison of strength differences and joint action durations between full and partial range-of-motion bench press exercise. *J Strength Cond Res* 13: 76–81, 1999.
18. Physical activity guidelines for Americans. *Okla Nurse* 53 (4): 25, 2008
19. Rhea, MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res* 18: 918–920, 2004.
20. Sanada, K, Kearns, CF, Midorikawa, T, and Abe, T. Prediction validation of total and regional skeletal muscle mass by ultrasound Japanese adults. *Eur J Appl Physiol* 96: 24–31, 2006.
21. Seynnes, OR, de Boer,M, and Narici, MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *J Appl Physiol* 102: 368–373, 2007.
22. Sulivan, JJ, DeVita, P, Brown, DD. Cardiovascular response to restricted range of motion resistance exercise. *J Strength Cond Res* 10: 3–7.
23. Young, A, Stokes, M, Round, JM, and Edwards, RH. The effect high-resistance training on the strength and cross-sectional area the human quadriceps. *Eur J Clin Invest* 13: 411–417, 1983.