Changes in Muscle Hypertrophy in Women with Periodized Resistance Training

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ABSTRACT

KRAEMER, W. J., B. C. NINDL, N. A. RATAMESS, L. A. GOTSHALK, J. S. VOLEK, S. J. FLECK, R. U. NEWTON, and K. HÄKKINEN. Changes in Muscle Hypertrophy in Women with Periodized Resistance Training. *Med. Sci. Sports Exerc.*, Vol. 36, No. 4, pp. 697–708, 2004. **Purpose:** Adaptations of arm and thigh muscle hypertrophy to different long-term periodized resistance training programs and the influence of upper body resistance training were examined. **Methods:** Eighty-five untrained women (mean age = 23.1 ± 3.5 yr) started in one of the following groups: total-body training [TP, $N = 18$ (3–8 RM training range) and TH, $N = 21$ (8–12 RM training range)], upper-body training [UP, $N = 21$ (3–8 RM training range) and UH, $N = 19$, (8–12 RM training range)], or a control group (CON, $N = 6$). Training took place on three alternating days per week for 24 wk. Assessments of body composition, muscular performance, and muscle cross-sectional area (CSA) via magnetic resonance imaging (MRI) were determined pretraining (T1), and after 12 (T2) and 24 wk (T3) of training. **Results:** Arm CSA increased at T2 (~11%) and T3 (~6%) in all training groups and thigh CSA increased at T2 (~3%) and T3 (~4.5%) only in TP and TH. Squat one-repetition maximum (1 RM) increased at T2 (~24%) and T3 (~11.5%) only in TP and TH and all training groups increased 1 RM bench press at T2 (~16.5%) and T3 (~12.4%). Peak power produced during loaded jump squats increased from T1 to T3 only in TP (12%) and TH (7%). Peak power during the ballistic bench press increased at T2 only in TP and increased from T1 to T3 in all training groups. **Conclusions:** Training specificity was supported (as sole upper-body training did not influence lower-body musculature) along with the inclusion of heavier loading ranges in a periodized resistance-training program. This may be advantageous in a total conditioning program directed at development of muscle tissue mass in young women. **Key Words:** WOMEN'S HEALTH, MRI, PERIODIZATION, PHYSICAL PERFORMANCE, PROGRESSIVE OVERLOAD, WEIGHT TRAINING

Resistance training has become a popular and important exercise component in a total conditioning program (i.e., muscle strength and endurance training) for women. Many programs have been studied that have been targeted at a variety of outcomes from improving a woman's physical performance to enhancing health outcomes (3,7,8,15,16,18–20,25,28,30). Yet, our understanding of the long-term (e.g., 6 months and longer) training effects on muscle hypertrophy, especially in the arm musculature, remains limited. Häkkinen et al. (7,8) have reported 7–10% cross-sectional area (CSA) increases in the total thigh muscle CSA of women after 6 months of resistance training. Examining a 6-month total-body conditioning program that included resistance training, loaded runs, endurance training, and agility type drills, Nindl et al. (25) demonstrated a significant increase in total thigh CSA from 249 + 14 cm^2 pretraining to 258 + 15 cm^2 with only the rectus femoris exhibiting a significant CSA increase when individual muscles were examined. The lack of hypertrophic changes in other thigh muscles was surprising and may be speculated to be due to host of reasons (e.g., exercises and loading protocols used). Nevertheless, this study warranted further research in this area with the goal of examining both thigh and arm musculature as well as comparing two different linear periodized training protocols with different loading schemes within a total conditioning program.

In younger women, the underlying muscle fiber hypertrophy that occurs with long-term training was eloquently demonstrated by Staron et al. (28). Muscle fiber hypertrophy of Type I (15%), Type IIA (45%), and IIAB+IIB (57%) were observed over 20 wk of a heavy resistance training program [i.e., 2 × wk, three sets of 6–8 repetition maximum (RM) in squats, vertical leg presses, leg extensions and leg curls] focused on the thigh musculature using several different exercises. Thus, the underlying mechanism for

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whole muscle changes was clear if the exercise program stimulus to the various muscles was adequate (i.e., if motor units were recruited). There is a need to better understand and compare the effects of different "real life" resistance training programs that are a composite of acute program variables. How they interact over time to mediate whole muscle hypertrophic adaptations in women is vital to improved exercise prescription and enhanced understanding of the adaptational plasticity of the neuromuscular system.

Classically, heavier resistances result in greater improvements in muscle strength with higher volume moderate load training also affecting muscle hypertrophy and lighter explosive loads improving maximal mechanical power (1). Yet from an untrained status, most heavy resistance training programs will see improvements in muscle strength and size. However, variation in resistances used in training appears to be important for long-term progression in resistance training (1,6). Within a periodized training program, resistance ranges have been varied using light (e.g., 12–15 repetition maximum [RM]), moderate (8–10 RM), and heavy (3–5 RM) resistances over a training cycle (1,6). However, no data are available quantifying the actual changes in muscular hypertrophy with the use of differential loads used in periodized training format. The use of a high resistance range in a periodized model may maximize the amount of muscle tissue that is activated (6). Heavier loading with fewer repetitions may also increase motor unit recruitment of muscle tissue and, not only maximize strength and power improvements but also maximize gains in muscle hypertrophy. Thus, we hypothesized that periodizing a resistance training program over a 6-month period of time by starting at an 8 RM load and proceeding to a 3 RM load would recruit more motor units and maximize strength and hypertrophy to a greater extent when compared with a periodization scheme starting at a 12 RM load and going to 8 RM load. In this study, we also sought to extend our understanding of the physiological changes that occur with the same type of training programs in which we have already documented performance related changes in women (16).

Although it is obvious that improvements in muscular strength and hypertrophy in women can be achieved, limited data exist examining the magnitude of hypertrophy in women's whole limb CSA and hypertrophy of the individual muscles when using different types of resistance training programs (4,5,28). Muscle hypertrophy is a multi-dimensional phenomenon, that is, based on loading (and motor unit recruitment), volume, as well as metabolic and hormonal aspects that have recently been shown to affect gene transcription and protein translation via mechanical signaling pathways. Thus, our rationale for comparing different programs was based on this multi-dimensional quality of muscle hypertrophy. In addition, alterations in variables (i.e., rest intervals, loading, volume) were vital because these types of design factors represent what is typically characterized as "hypertrophy" or "strength/power" programs. Finally, few data are available measuring changes due to upper-body-only resistance training in women (16). Essentially, we wanted to examine the effects of two high load but slightly different loading protocols (3–8 vs 8–12) in a periodized format on whole and individual muscle hypertrophy and upper versus whole body training. Therefore, the primary purposes of the present study were: 1) to compare changes in whole muscle hypertrophy and the associated strength and power changes with different long-term resistance training programs and 2) to determine the influence of upper-body-only resistance training on muscular hypertrophy of both the thighs and the arm musculature.

METHODS

Experimental approach. Two resistance ranges were used to vary the program over time a 6-month period of time. We have previously reported the elements of these total conditioning programs in detail that included a resistance-training program and a supplemental endurance program (16). Each program was divided into total- and upper-body-only training groups. The heavy loading was based on a classical periodization model (e.g., intensity increased while volume decreased with each training phase), thereby training was cycled from a starting point of 8 RM loading to an end point of 3 RM loading over a 3-month mesocycle (see Table 2). Two mesocycles were used in this study. For the lighter resistance range, the intensity started at 12 RM and ended with 8 RM loading. Thus, four training groups along with a control group provided the basic design. The resistance variations were kept within each of these intensity loading ranges but were varied over the training program in a periodized format (16). We carefully monitored and controlled the conditions (i.e., individual trainers for each woman) to ensure proper technique and progression in each program (22). Assessments were performed at 0 (T1), 12 (T2), and 24 (T3) weeks and included maximal strength and power testing, body composition, and determination of arm and thigh muscle CSA using MRI. This approach allowed us to evaluate the effects of different training programs and to compare upper-body-only training to total body training. We felt that the results of this investigation would provide new adaptational insights into "real life" strength and conditioning programs for women. Each program is therefore a composite interaction of its design and influence of each of the acute program variables (i.e., choice, order, rest, load, and sets) and therefore presents a specific physiological and biomechanical training stimulus to the body. Classically, changes in the volume and intensity of the workouts are the primary factors periodized over time along with planned periods of rest thereby allowing variation in the exercise stimuli.

Participants. Untrained but physically active, college-aged women volunteered to participate in this study after having all of the risks explained to them before the investigation. Each participant signed an informed consent document which was approved by the university's Institutional Review Board for the Use of Human Subjects and by the Human Use Review Office of the U.S. Army Surgeon General. Our procedures were in accordance with the guidelines for use of human subjects set forth by the American College of Sports Medicine.

TABLE 1. Participant characteristics by group.

Group	Age (yr)	Height (cm)	BM (kg)	Body Fat (%)
TP ($N = 18$)	22.4 ± 3.5	163.7 ± 7.5	64.1 ± 8.8	25.8 ± 5.9
UP ($N = 21$)	22.7 ± 4.0	165.5 ± 7.2	66.7 ± 10.7	25.5 ± 6.1
TH ($N = 21$)	23.8 ± 3.7	165.4 ± 5.4	63.2 ± 7.0	23.9 ± 5.0
UH ($N = 19$)	23.5 ± 3.7	166.7 ± 6.2	65.7 ± 12.1	26.3 ± 5.3
CON ($N = 6$)	23.1 ± 2.4	164.5 ± 6.2	65.9 ± 11.2	26.5 ± 4.2

CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

Before initiation of the study, all participants were medically screened by a physician for orthopedic problems, endocrine disorders, eating disorders, pregnancy, or any other medical problems, which could have compromised the safety for participation or confounded the results of the study.

Participants were initially matched for age, height, body mass, and one-repetition maximum (1 RM) squat and bench press performance, physical activity history, and then randomly placed into one of the after experimental groups: The final group N sizes after the study were as follows: Total-body training groups [TP, $N = 18$ (3–8 RM training range) and TH, $N = 21$ (8–12 RM training range)], upper-body training groups [UP, $N = 21$ (3–8 RM training range) and UH, $N = 19$, (8–12 RM training range)], or a control group (CON, $N = 6$). Group characteristics are shown in Table 1. Before initiation of the study, all individuals participated in a 2-wk familiarization period to accustom themselves to the testing and training procedures. Thus, special care was taken to remove learning effects that could potentially overestimate performance increases. Compliance for the total number of training sessions was 100% as any missed workouts were made up as quickly as possible within a training week.

Body composition. Body composition was assessed using the seven-site skinfold method (26). The same investigator obtained all measures on the right side of each participant's body. Skinfold thickness was obtained using a Lange skinfold caliper at the chest, mid-axilla, triceps, subscapular, abdominal, suprailiac, and thigh regions using procedures previously described (26). Repeated trials were performed until two measures within 1 mm were obtained, with the mean of these two measures utilized to estimate body density using the equation of Jackson et al. (11). Percent body fat was subsequently calculated using the Siri equation (27). Fat-free mass was subsequently calculated using body mass and percent body fat and body mass index (BMI) determined using the equation body mass (kg)/height^2 (m). Body composition assessments were performed at T1, T2, and T3.

TABLE 2. Example training programs for the total body and upper body training groups.

Group	Exercise	Sets × Repetitions (Week Number)*	Rest Periods
TP	Dumbbell clean and press	3 × 8 RM (1–3); 3 × 5 RM (4–9); 3 × 3 RM (10–12)	2 min
	Leg curl	3 × 8 RM (1–9); 3 × 6 RM (10–12)	2 min
	Dumbbell incline press	3 × 8 RM (1–3); 3 × 5 RM (4–9); 3 × 3 RM (10–12)	2 min
	Front lat pull-down	3 × 8 RM (1–9); 3 × 6 RM (10–12)	2 min
	Back squat	3 × 8 RM (1–3); 3 × 5 RM (4–9); 3 × 3 RM (10–12)	2 min
	Incline sit-up	3 × 15 RM (1–12)	2 min
	Upright row	3 × 8 RM (1–9); 3 × 5 RM (10–12)	2 min
	Dumbbell row	3 × 8 RM (1–9); 3 × 5 RM (10–12)	2 min
TH	Back squat	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60–90 s
	Leg extension	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	30–60 s
	Leg curl	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	30–60 s
	Dumbbell incline press	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60 s
	Chest flye	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60 s
	Front lat pull-down	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60 s
	Upright row	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	30 s
	Dumbbell row	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	30 s
	Rotational crunch	3 × 25 RM (1–12)	60 s
UP	Bench press	3 × 8 RM (1–3); 3 × 5 RM (4–9); 3 × 3 RM (10–12)	2 min
	Seated row	3 × 8 RM (1–3); 3 × 5 RM (4–9); 3 × 3 RM (10–12)	2 min
	Dumbbell press	3 × 8 RM (1–3); 3 × 5 RM (4–9); 3 × 3 RM (10–12)	2 min
	Front lat pull-down	3 × 8 RM (1–9); 3 × 6 RM (10–12)	2 min
	Standing arm curl	3 × 8 RM (1–9); 3 × 6 RM (10–12)	2 min
	Triceps pushdown	3 × 8 RM (1–9); 3 × 6 RM (10–12)	2 min
	Incline sit-up	3 × 20 RM (1–12)	2 min
	Back extension	3 × 8 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	2 min
UH	Bench press	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60–90 s
	Seated row	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60–90 s
	Dumbbell shoulder press	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60 s
	Front lat pull-down	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	60 s
	Standing arm curl	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	30 s
	Triceps pushdown	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	30 s
	Rotational crunch	3 × 25 RM (1–3); 3 × 10 RM (4–9); 3 × 30 RM (10–12)	30–60 s
	Back extension	3 × 12 RM (1–3); 3 × 10 RM (4–9); 3 × 8 RM (10–12)	30–60 s

* The programs listed above represent the first 12-wk resistance training period. This periodized training program was then repeated for weeks 13–24.

Muscle cross-sectional area (CSA). The CSA of the mid thigh and mid upper arm of the dominant limbs was assessed at T1, T2, and T3 via MRI technology using a 0.5 T superconduction magnet (Picker International, Highland Heights, OH) with MR6B software as previously described (15). Images were obtained by alteration of the spin-lattice or longitudinal relaxation time (T1). T1-weighted images were obtained using repetition time of 500 ms, echo time of 13 ms, radio frequency of 90°, and power absorption of 0.028 $W \cdot kg^{-1}$. Muscle CSA was analyzed from the MRI scans by a gradient echo technique that allowed the greatest delineation and distinction between muscles. Once the individual was positioned within the magnet, the thigh of the dominant leg was supported under the knee so that the thigh was parallel to the MRI table, and the feet were strapped together to prevent rotation. The arm was positioned in a moderately internally rotated position with the palm of the hand on the thigh, and support was placed under the shoulder and elbow so that the upper arm was parallel to the MRI table. Sagittal images of the thigh and upper arm were obtained, and a 15-slice grid was placed over the sagittal image and transaxial images were obtained. Fifteen 1-cm-thick transaxial images were obtained at equal distances between the base of the femoral head and mid-knee joint of the thigh, and the superior head of the humerus and mid-elbow joint of the upper arm. All MRI images were then exported to a Macintosh Quadra computer for calculation of total and individual muscle CSA with a modified National Institute of Health (NIH) image software package. For the thigh CSA, slice 8 was used (slice 1 being the base of the femoral head); for the upper arm, slice 9 was used (slice 1 being at the superior aspect of the humerus). One slice more distal was used for the upper arm to ensure inclusion of the brachialis muscle. Tissue CSA was obtained using a Maxitron displayer and Adobe program, and the NIH 1.55.20A Image Analysis pixel-counting program. Total area, bone area, and fat-free mass were determined for the rectus femoris, vastus lateralis, vastus intermedius, vastus medialis, sartortius, biceps femoris short head, biceps femoris long head, semitendinosis, semimembranosis, gracilis, adductor group, biceps brachii, brachialis, and triceps brachii. The same investigator performed all measurements and the test-retest reliability intraclass correlation coefficient was $R = 0.99$.

Strength assessments. Maximal strength was assessed using the 1 RM squat and bench press exercises performed on the Plyometric Power System (PPS) (Norsearch, Lismore, Australia) using previously described testing procedures (14). For the squat, each participant descended to the parallel position (by flexing the knees and hips until the greater trochanter of the femur reached the same horizontal plane as the superior border of the patella) and upon a verbal signal from the tester ascended to the upright starting position while maintaining proper form and technique throughout the lift. For the bench press, each participant lowered the bar until contact with the chest was achieved and subsequently lifted the bar back to the fully extended elbow position. Any trials failing to meet the standardized technique criteria were discarded. A warm-up consisting of 5–10 repetitions with approximately 40–60% of perceived maximum was performed. Then, a second warm-up set consisting of three to five repetitions with approximately 60–80% of perceived maximum was performed. Each subsequent trial was performed for one repetition with progressively heavier weight until the 1 RM was determined. Using this protocol the 1 RM was determined within three to five attempts, using 3- to 5-min rest periods between trials.

Power assessments. Lower- and upper-body power assessments were also performed on the PPS. Lower-body power was assessed using the jump squat and upper body power using the ballistic bench press. After a general warm-up, power was determined by having each participant perform three maximal trials at each of three resistances of 30, 60, and 90% of her respective 1 RM (determined at T1, T2, and T3) with 2 min of rest between all trials. These loads span the concentric force spectrum corresponding to a light, moderate, and heavy load and provide quantification of power output and possible load specific training adaptations as demonstrated in our previous research (24). The inclusion of three loading regimens enabled us to examine peak power production at various intensities, as the magnitude of loading has been shown to significantly affect power output (31). In addition, inclusion of the jump squat with 90% of 1 RM was more specific to the training loads used throughout the study. After determination of jump squat power, maximal bench press power was determined using three trials of the ballistic bench press at 30% of each subject's 1 RM with 2 min of rest between trials. After determination of jump squat power, maximal bench press power was determined using three trials of the ballistic bench press at 30% of each participant's 1 RM with 2 min of rest between trials.

The PPS allows the performance of ballistic exercises and has been described in detail elsewhere (16). For both exercises, the weight was released upon jumping/throwing and bar displacement was calculated. To perform a jump squat, the participant descended to a position in which the thigh musculature was parallel to the ground. Then in a ballistic manner, the participant ascended as rapidly as possible and proceeded to jump as high as possible while minimizing any contributions from the arms. To perform a ballistic bench press, the participant lowered the weight until contact with the pectoral muscles was observed and subsequently lifted and released the weight in a ballistic manner upon reaching complete elbow extension. The PPS incorporates a unidirectional electromagnetic braking system that immediately prevented descending bar movement once engaged allowing the safe performance of the jump squat and ballistic bench press. A rotary encoder attached to the PPS and interfaced with a computer enabled measurement of bar movement with an accuracy of 0.001 m. Customized software was used to calculate peak power for each trial and the highest value obtained per load was used for statistical analysis.

Conditioning programs. We have previously described the conditioning programs used in the present study (16). In brief, all individuals (with the exception of the

TABLE 3. Differences in body composition during the resistance-training period.

Group	Body Mass (kg)	% Body Fat	Fat-Free Mass (kg)	BMI (kg · m^{-2})
TP				
T1	64.0 ± 8.8	25.8 ± 5.9	47.2 ± 4.7	23.9 ± 2.9
T2	65.8 ± 10.1	26.0 ± 5.7	48.3 ± 5.0*	24.6 ± 3.3*
T3	67.0 ± 10.2*@	26.2 ± 5.4	49.1 ± 5.4*@	25.0 ± 3.5*
TH				
T1	63.7 ± 7.1	24.1 ± 5.5	47.4 ± 2.9	23.2 ± 2.2
T2	64.0 ± 7.0	23.1 ± 4.9#	48.3 ± 2.8	23.3 ± 2.2
T3	64.9 ± 7.3#	23.7 ± 5.1#	48.6 ± 3.1*	23.6 ± 2.3
UP				
T1	65.0 ± 11.3	25.3 ± 6.0	48.0 ± 5.9	23.7 ± 3.6
T2	64.9 ± 11.3	24.3 ± 5.7#	48.7 ± 6.4	23.7 ± 3.6#
T3	65.0 ± 9.8#	24.2 ± 5.2#	49.0 ± 5.9	23.8 ± 3.0#
UH				
T1	64.3 ± 11.8	26.2 ± 5.3	47.0 ± 5.6	23.2 ± 3.0#
T2	64.3 ± 11.5	25.2 ± 5.2#	47.7 ± 6.2	23.2 ± 3.0#
T3	65.4 ± 11.8	25.6 ± 5.6#	48.2 ± 5.9*	23.6 ± 3.1#
CON				
T1	65.9 ± 11.2	26.5 ± 4.2	48.4 ± 3.7	24.4 ± 3.8
T2	65.8 ± 11.5	25.9 ± 4.9	48.8 ± 4.1	24.3 ± 3.7
T3	65.9 ± 11.4	26.2 ± 3.9	48.6 ± 3.9	24.4 ± 3.9

* $P < 0.05$ from corresponding time point T1.
@ $P < 0.05$ from corresponding time point T2.
# $P < 0.05$ between groups.
CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

control group) participated in a 24-wk periodized resistance training program performed on three alternating days per week. The 24-wk program consisted of free weight and machine exercises and was divided into two 12-wk mesocycles, each consisting of three short microcycles (see Table 2 for details). To complete the total conditioning program, all of the training groups participated in a standard aerobic training program consisting of 25–35 min in duration at an intensity of 70–85% of maximum heart rate 3 d·wk^{-1}. The program was intentionally designed to be similar to the study by Volpe et al. (29) so as to not negatively impact strength or power development. All sessions were individually supervised by certified strength and conditioning specialists who directly monitored all training sessions to optimize the training adaptations (22).

Statistical analyses. All data are presented as the mean ± SD. Data were analyzed using a 5 × 3 (group × time) repeated measures analysis of variance (ANOVA). When significant main effects and/or interactions were observed, a Fisher's least significant difference or Tukey's *post hoc* test was used where appropriate to determine pairwise differences. Test-retest reliability intraclass Rs for the dependent variables was $R \geq 0.95$. Statistical power calculations for this study ranged from 0.78 to 0.95. The level of significance set for the investigation was $P \leq 0.05$.

RESULTS

Body composition. Differences in body composition over time are presented in Table 3. There was a significant increase in body mass at T3 for the TP group only, whereas no significant differences were observed in TH and UH groups. However, all training groups except the UP group significantly increased fat-free mass at T3. The TP group showed the only significant increase in fat-free mass at T2 and significant increase from T2 to T3. No significant changes were observed in percent body fat for any group at any time point. However, percent body fat was significantly lower in TH than TP at T2 and T3. Body mass index increased significantly at T2 and from T2 to T3 in the TP group only. At T3, significant increases in BMI were observed only in TP. Fat mass reductions did not reach statistical significance in any group. No differences were observed in the CON group at any time point for any body composition variable.

Muscle CSA. Differences in arm and thigh CSA are presented in Figure 1. For arm CSA, all training groups increased significantly at T2 (TP = 6.6%; TH = 15.0%; UP = 11.7%; UH = 13.4%). In addition, all training groups showed significant increases between T2 and T3 (TP = 6.6%; TH = 4.3%; UP = 7.8%; UH = 5.2%). Collectively, these changes represented ~11% increase from T1 to T2 and a further ~6% increase from T2 to T3. For thigh CSA, only the total-body training groups exhibited hypertrophy from T1 to T2 (TP = 4.5%; TH = 2.7%) and from T2 to T3 (TP = 4.8%; TH = 4.2%). At T2 and T3, the CSA of the thigh was significantly greater for the total-body groups compared with the upper-body groups. No differences were observed in the CON group at any time point for thigh or arm.

The CSA of individual muscles are presented in Tables 4–6. Significant increases in muscle CSA were observed in all training groups at T2 and T3 compared with T1 in the brachialis, biceps brachii, and triceps brachii muscles (Table 4). From T2 to T3, significant increases were observed in all training groups for the biceps brachii, whereas significant increases were only observed in the TP and TH groups for the brachialis and in the TP and UP groups for the triceps brachii. Significant increases in CSA of the hamstring and adductor muscle groups were observed only in the TP and TH groups (Table 5). Significant increases at T2 and T3 (compared to T1 and T2) were observed in the TP group for the biceps femoris in both the long and short heads, semitendinosus, and adductor group, whereas semimembranosus

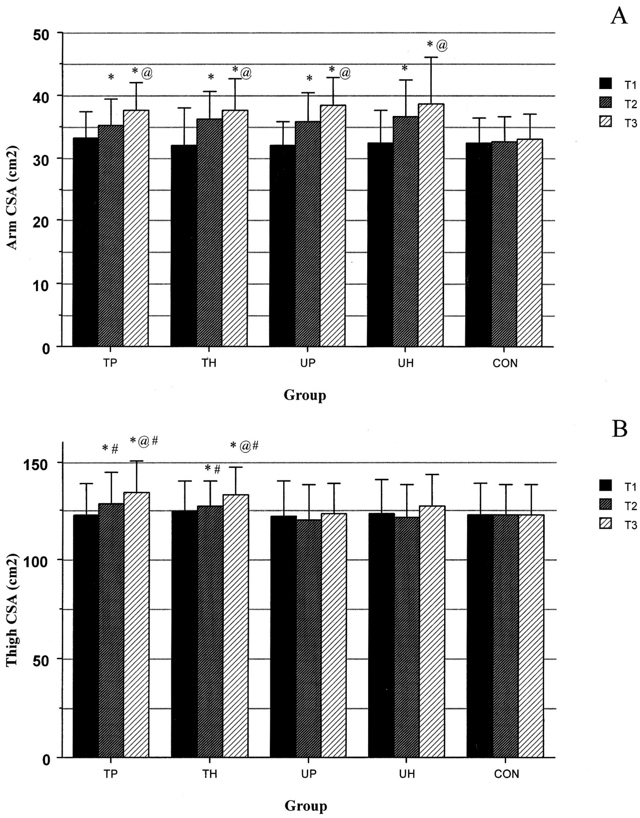

FIGURE 1—Differences in arm (A) and thigh (B) cross-sectional area (cm²) at 0 (T1), 3 (T2), and 6 (T3) months of training. * $P < 0.05$ from corresponding time point T1; @ $P < 0.05$ from corresponding time point T2; # $P < 0.05$ compared with UP and UH. Data presented are means ± SD. CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

CSA increased at T2 but did not show a further increase at T3. In TH, significant increases were observed at T3 compared with T1 for the biceps femoris short head and adductor group at T2 compared with T1 and T3 compared with T2 for the semitendinosus, whereas no significant changes were observed for the biceps femoris (long head) and semimembranosus. Significant reductions in CSA of the semimembranosus were observed in T2 and T3 in the UP and UH groups. Significant increases at T2 and T3 compared with T1 and T2 in all three vasti muscles, gracilis, and rectus femoris were observed in the TP group, whereas an increase was only observed at T3 compared with T1 and T2 in the sartorius (Table 6). For the TH group, significant increases were observed at T2 and T3 compared with T1 and T2 for the vastus medialis and lateralis muscles, significant increases at T2 with no further increases at T3 compared with T2 were observed for the gracilis and vastus intermedius, and significant increases only at T3 compared with T1 were observed for the sartorius and rectus femoris. Significant reductions in vastus intermedius CSA at T2 and T3 compared with T1 were observed in the UP and UH groups. No differences were observed for any muscle CSA at any time point in the CON group.

Maximal strength. Differences in maximal strength are presented in Figure 2. For the 1 RM squat, two of the four training groups demonstrated significant increases at T2 (TP = 25.2%; TH = 23.8%) and T3 (TP = 12.7%; TH = 10.5%). At T2 and T3, both total-body groups had significantly greater 1 RM squat values than both of the upper-body groups. Trends for an increase in 1 RM squat were observed between T1 and T3 for both the UP and UH groups (P = 0.08 and 0.10, respectively). All training groups significantly increased 1 RM bench press at T2 (TP = 19.8%; TH = 15.8%; UP = 16.4%; UH = 14.0%) and T3 (TP = 13.8%; TH = 11.2%; UP = 12.3%; UH = 12.3%). No differences were observed in the CON group at any time point for either variable.

Muscular power. Differences in muscular power during the jump squat are presented in Figure 3. Peak power produced at 30% of 1 RM increased significantly from T1 to T3 only in the TP and TH groups (11.8 vs 7.2%, respectively). Delta change in 30% peak power from T1 to T3 was significantly greater in the TP group than the UP group. During jump squats with 60% of 1 RM, peak power increased significantly from T1 to T3 in the TP and TH groups. No differences were observed among groups in 60% peak power at T2 or T3. Delta changes in 60% peak power from T1 to T3 were significantly greater in the TP and TH groups compared to UP. During jump squats with 90% of 1 RM, peak power increased significantly from T1 to T3 in the TP and TH groups. In addition, the TP group increased from T1 to T2. Delta changes in 90% peak power from T1 to T3 were significantly greater in the TP and TH groups than UP.

Differences in peak power produced during the ballistic bench press with 30% of 1 RM are presented in Figure 4. No significant training effects for peak power were observed from T1 to T2 except in the TP group. However, ballistic bench press peak power increased significantly from T1 to T3 in all training groups. Delta change in peak power from

TABLE 4. Changes in CSA of the upper arm muscles during the resistance-training period.

Group	Brachialis (cm²)	Biceps Brachii (cm²)	Triceps Brachii (cm²)
TP			
T1	4.71 ± 0.61	7.69 ± 1.20	20.28 ± 3.12
T2	4.99 ± 0.78*	8.07 ± 1.34*	21.29 ± 2.98*
T3	5.25 ± 0.69*@	8.77 ± 1.32*@	22.70 ± 2.95*@
TH			
T1	4.08 ± 0.77	8.18 ± 1.46	19.98 ± 4.04
T2	4.55 ± 0.79*	8.67 ± 1.43*	21.87 ± 3.45*
T3	5.10 ± 0.91*@	9.25 ± 1.99*@	22.68 ± 3.60*
UP			
T1	4.26 ± 0.83	7.70 ± 1.01	19.55 ± 2.85
T2	4.69 ± 0.78*	8.52 ± 1.43*	21.52 ± 3.14*
T3	4.71 ± 0.60*	9.08 ± 1.36*@	23.36 ± 2.82*@
UH			
T1	4.89 ± 0.91	7.77 ± 1.66	19.70 ± 3.39
T2	5.24 ± 0.87*	8.47 ± 2.00*	22.16 ± 3.63*
T3	5.27 ± 1.09*	9.05 ± 2.27*@	23.25 ± 4.47*
CON			
T1	4.60 ± 0.65	7.75 ± 1.26	19.61 ± 3.16
T2	4.62 ± 0.71	7.78 ± 1.31	19.58 ± 3.25
T3	4.55 ± 0.68	7.79 ± 1.27	19.67 ± 3.41

* $P < 0.05$ from corresponding time point T1.
@ $P < 0.05$ from corresponding time point T2.
CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

TABLE 5. Changes in CSA of the hamstring and adductor groups during the resistance-training period.

Group	Adductors (cm^2)	Biceps Femoris (Short Head) (cm^2)	Biceps Femoris (Long Head) (cm^2)	Semimembran. (cm^2)	Semitendinosus (cm^2)
TP					
T1	22.07 ± 4.15	2.21 ± 0.69	12.81 ± 2.47	7.22 ± 2.01	7.88 ± 2.63
T2	23.09 ± 4.12*	2.28 ± 0.66*	13.30 ± 1.63*	7.71 ± 2.05*	8.55 ± 2.77*
T3	24.36 ± 4.68*@	2.41 ± 0.68*@	14.03 ± 1.95*@	7.88 ± 1.94*	9.02 ± 2.86*@
TH					
T1	23.36 ± 6.06	1.84 ± 0.67	12.12 ± 2.95	8.34 ± 1.86	7.28 ± 1.61
T2	22.96 ± 5.28	1.87 ± 0.64	12.14 ± 2.23	8.17 ± 1.68	7.62 ± 1.45*
T3	24.25 ± 5.74*	1.98 ± 0.73*	12.34 ± 2.41	8.46 ± 1.93	8.14 ± 1.57*@
UP					
T1	22.54 ± 4.07	2.06 ± 0.61	11.56 ± 2.39	8.20 ± 2.88	7.79 ± 1.58
T2	21.50 ± 4.10	2.00 ± 0.57	11.10 ± 2.03	7.69 ± 2.39*	7.38 ± 1.40
T3	22.34 ± 4.32	1.94 ± 0.62	11.46 ± 1.94	7.70 ± 2.14*	7.61 ± 1.62
UH					
T1	22.02 ± 4.99	2.11 ± 0.67	11.95 ± 1.87	8.16 ± 2.06	7.73 ± 2.23
T2	21.24 ± 4.35	2.11 ± 0.71	11.91 ± 1.88	7.74 ± 1.98*	7.56 ± 1.92
T3	22.60 ± 4.94	2.02 ± 0.70	12.09 ± 1.92	7.33 ± 1.55*@	7.85 ± 2.03
CON					
T1	21.01 ± 4.61	1.98 ± 0.66	11.54 ± 2.11	8.02 ± 1.96	7.70 ± 2.16
T2	20.94 ± 4.81	1.94 ± 0.68	11.50 ± 2.28	7.88 ± 1.88	7.62 ± 1.99
T3	20.91 ± 4.66	1.99 ± 0.71	11.45 ± 2.18	7.89 ± 1.97	7.67 ± 2.01

* $P < 0.05$ from corresponding time point T1.
@ $P < 0.05$ from corresponding time point T2.
CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

T1 to T3 was greatest in the TP group (68 W). However, no significant differences were observed in the delta changes among any groups.

DISCUSSION

In general, we showed two heavy resistance exercise training protocols appeared to be effective in producing an increase strength, hypertrophy, and power in previously untrained women. In addition, the TP protocol tended to show a higher frequency of significant increases in individual muscle CSA between T2 and T3. The protocols that used upper-body training alone held to the principle of training specificity and produced neither significant gains in whole-body muscular performance nor hypertrophy in the lower body musculature. This study provides some novel insights into the changes in arm and the thigh musculature of women using MRI technology muscular hypertrophy consequent to different conditioning protocols.

The changes in body composition represent a first layer of observation when examining changes in the tissue compartments. Although limited by the use skinfold analyses, our findings were similar to other studies in the literature with fat-free mass increases ranging from 2 to 4% (3,20,28). No significant differences were observed in the UP group, suggesting not enough overall tissue mass was affected by the program to yield a change. Hinting at the differential rate and morphological geography of fat-free mass deposition, another resistance training study by Chilibeck et al. (4) examining just the arms, reported significant increases in

TABLE 6. Changes in CSA of the quadriceps and other thigh muscles during the resistance-training period.

Group	Gracilis (cm^2)	RF (cm^2)	VL (cm^2)	VI (cm^2)	VM (cm^2)	Sartorius (cm^2)
TP						
T1	4.35 ± 0.88	6.65 ± 1.67	21.73 ± 3.49	20.46 ± 3.22	12.29 ± 1.89	3.85 ± 0.97
T2	4.79 ± 1.12*	6.96 ± 1.57*	22.86 ± 3.57*	20.98 ± 3.02*	12.81 ± 2.26*	4.02 ± 0.92
T3	5.10 ± 1.07*@	7.33 ± 1.35*@	23.99 ± 3.31*@	21.75 ± 3.00*@	13.39 ± 2.24*@	4.29 ± 1.19*@
TH						
T1	4.37 ± 1.20	6.34 ± 1.20	22.99 ± 3.30	20.86 ± 2.83	12.73 ± 2.74	3.36 ± 1.37
T2	4.72 ± 1.29*	6.51 ± 1.10	24.17 ± 2.85*	21.42 ± 2.88*	13.03 ± 2.79*	3.55 ± 1.02
T3	4.96 ± 1.41*	6.72 ± 1.14*	25.15 ± 3.13*@	21.78 ± 3.26*	13.42 ± 3.19*@	3.66 ± 1.15*
UP						
T1	4.40 ± 0.97	6.50 ± 1.52	21.82 ± 3.48	20.15 ± 3.55	12.67 ± 2.63	3.47 ± 1.13
T2	4.19 ± 0.99	6.37 ± 1.43	21.56 ± 4.05	19.53 ± 3.80*	12.41 ± 2.25	3.37 ± 0.97
T3	4.25 ± 0.84	6.57 ± 1.24	21.93 ± 3.18	19.46 ± 3.40*	12.45 ± 1.96	3.52 ± 1.08
UH						
T1	4.39 ± 0.95	6.73 ± 1.62	22.07 ± 3.69	19.86 ± 3.26	12.57 ± 2.66	3.60 ± 0.81
T2	4.18 ± 0.82	6.47 ± 1.30	21.94 ± 3.55	19.05 ± 2.69*	12.19 ± 2.78	3.33 ± 0.71
T3	4.28 ± 0.88	6.64 ± 1.36	22.87 ± 3.63	19.42 ± 3.12*	12.54 ± 2.64	3.52 ± 0.80
CON						
T1	4.28 ± 0.91	6.60 ± 1.61	22.01 ± 3.86	20.14 ± 3.17	12.40 ± 2.96	3.52 ± 0.86
T2	4.22 ± 0.88	6.57 ± 1.50	21.94 ± 3.68	20.17 ± 3.28	12.28 ± 2.78	3.47 ± 0.99
T3	4.26 ± 0.94	6.63 ± 1.66	21.99 ± 3.71	20.08 ± 3.18	12.29 ± 2.97	3.49 ± 0.89

* $P < 0.05$ from corresponding time point T1.
@ $P < 0.05$ from corresponding time point T2.
RF, rectus femoris; VL, vastus lateralis; VI, vastus intermedius; VM, vastus medialis; CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

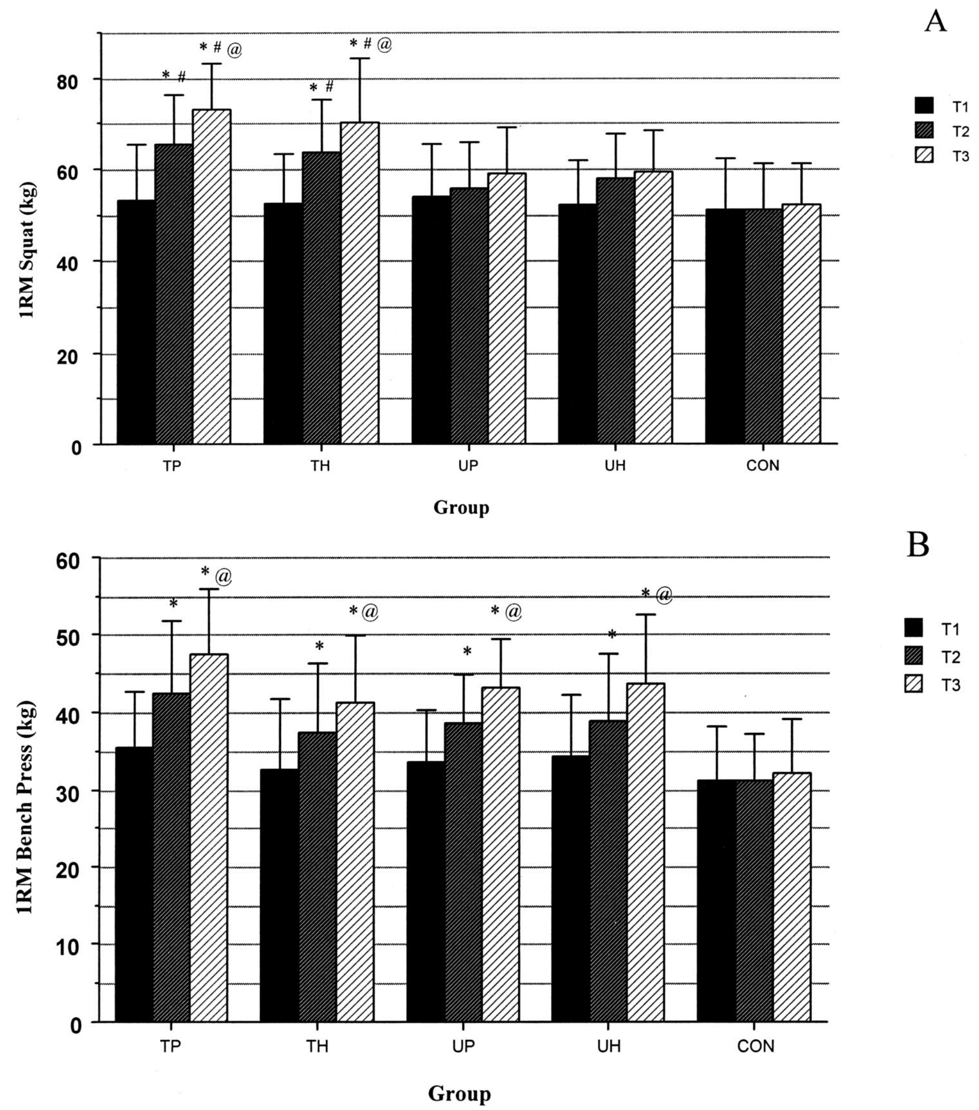

FIGURE 2—Differences in 1 RM squat (A) and bench press (B) at 0 (T1), 3 (T2), and 6 (T3) months of training. * $P < 0.05$ from corresponding time point T1; @ $P < 0.05$ from corresponding time point T2; # $P < 0.05$ compared with changes in UP and UH. Data presented are means ± SD. CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

upper-arm lean tissue only after the first 10 wk of a 20-wk training program. In the present study, the lack of a significant decrease in percent body fat consequent to 6 months of conditioning was surprising. However, it supports our contention that the endurance-training program was not a primary focus or a greater caloric expenditure would have been expected to occur thereby mediating potential fat mass reductions (18,20,21). In addition, we did not make any attempts to control kilocaloric intakes beyond assuring a normal dietary profile with our dietetic support team. Some insights to our current findings may be gained from another study by our group in which we showed that diet and kilocalorie intake control may be the most influential variables affecting body fat reductions during an exercise training program (19).

Upper-arm CSA increased significantly in all groups from T1 to T2, T2 to T3, and T1 to T3, which supports previous studies examining 16 (5) and 20 (2–4) wk of resistance training. Unique to this investigation was the use of MRI to measure CSA of the triceps brachii, biceps brachii, and brachialis muscles in response to periodized resistance training in women. Increases in CSA were observed from T1 to T2 and continued from T2 to T3 in these muscles (with the exception of the brachialis in the UP and UH groups and triceps brachii in the TH and UH groups). These types of changes have not consistently been shown in women during resistance training and may be due to differences in many factors related to program design (e.g., intensity, posture). Chilibeck et al. (4) reported increases in arm lean tissue mass after 10 wk of a 20-wk program, but no further significant increase from 10 to 20 wk of the program. The TP and TH groups showed continued gains in upper and lower body muscle CSA throughout the 24 wk of training. Thus, it appears that variation in program design may be important for continued long-term increases in arm and thigh muscle CSA in women. In comparison with the literature, the results of the present study provide direct evidence for the use of periodization in resistance training programs

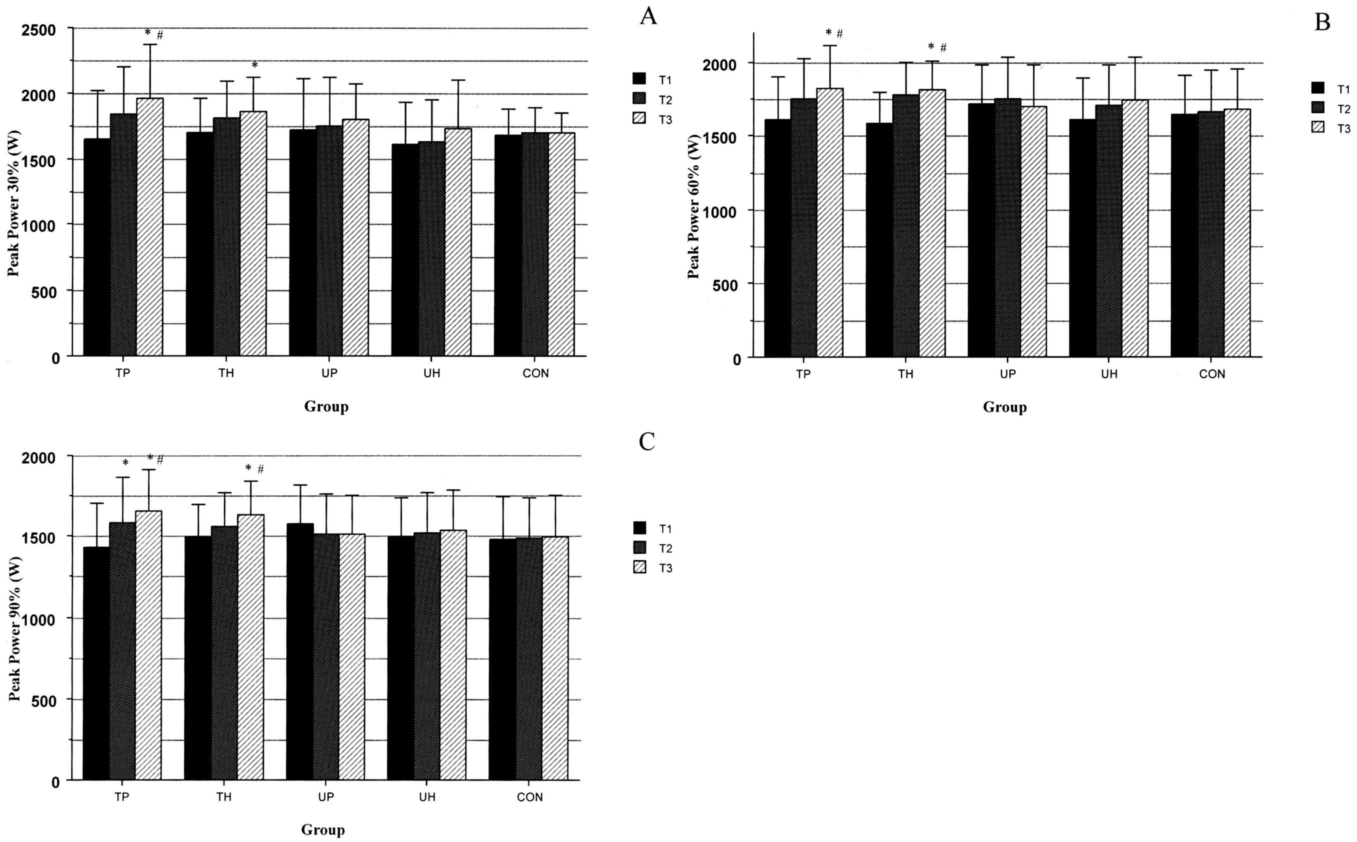

FIGURE 3—Differences in jump squat peak power (W) at 30% (A), 60% (B), and 90% (C) of 1 RM at 0 (T1), 3 (T2), and 6 (T3) months of training. * $P < 0.05$ from corresponding time point T1; # $P < 0.05$ compared with UP and UH. Data presented are means ± SD. CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

for women in order to achieve continued increases in muscle hypertrophy over an entire 6-month training period. Of both practical and scientific importance, while the total arm CSA was observed to increase in all of the training groups, only the TP group demonstrated continued increases in all three of the arm muscles (see Table 4). This argues for the training concept that total-body resistance training augments the changes observed with upper body resistance training.

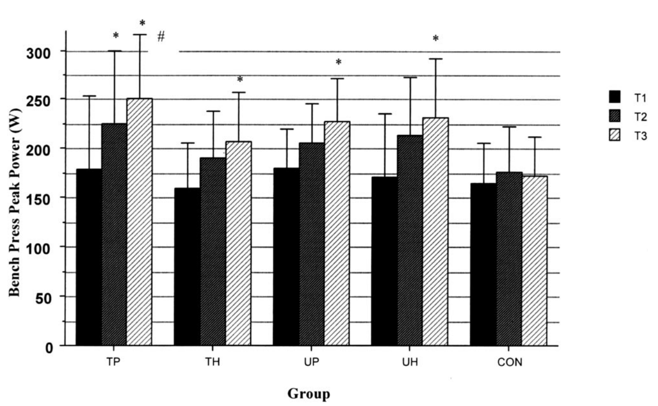

FIGURE 4—Differences in bench press peak power (W) at 30% of 1 RM at 0 (T1), 3 (T2), and 6 (T3) months of training. Data presented are means ± SD * $P < 0.05$ from corresponding time point T1; # $P < 0.05$ compared to all groups from T1 to T3. CON, control group; UP, upper body, 3–8 RM; UH, upper body, 8–12 RM; TP, total body, 3–8 RM; TH, total body, 8–12 RM.

Increases in thigh CSA were only observed for the total-body groups in the present study. This was not surprising, as the principle of training specificity would dictate that only improvements would occur in the trained musculature and only the TP and TH groups performed lower-body resistance exercises. However, more consistent gains in CSA of most thigh muscles investigated were observed in the TP group (Tables 5 and 6). Compared with upper-arm hypertrophy, the relative increase observed in thigh CSA was less (17 vs 8% in both total-body groups). Chilibeck et al. (3,4) and Calder et al. (2) reported approximate increases of 3% in leg muscle mass compared with a 10% increase in the arms after 20 wk of resistance training. Häkkinen et al. (7) reported a 10% increase in quadriceps CSA after 6 months of heavy resistance training. Interestingly, Cureton et al. (5) reported a significant increase in total arm CSA with no increase in total thigh CSA after 16 wk of resistance training. Part of this may be due to the relative size of each muscle mass examined (i.e., leg musculature is larger than arm musculature and subsequently would show less relative increase). In addition, it has been suggested that differences in the magnitude of hypertrophy of the arms and legs in previously untrained women may be due to arm musculature being less trained at the start of a training program compared with the legs (4,5). Regardless of the exact mechanism, our data are consistent with these previous studies showing greater relative gains in arm versus leg CSA in previously untrained women.

Similar to the arm musculature, the TP group demonstrated increases in hypertrophy from T1 to T2 and T2 to T3 in all individual muscles of the thigh, with the exception of the semimembranosus (see Tables 5 and 6). Interestingly, the TH group demonstrated increased hypertrophy of fewer individual muscles of the thigh and made significant increases in hypertrophy from T2 to T3 in only 3 of the 11 muscles examined. This differential adaptation occurred despite both total-body training groups showing similar increases in total thigh CSA measures.

Similar to previous studies, we used a total conditioning program to study the effects of a resistance training program. Although the endurance-training program utilized in the present study has been shown to improve endurance performance in untrained women (16), it was not a primary focus of the conditioning program. Previous studies have demonstrated the potential incompatibility between high-intensity resistance and high-intensity aerobic exercise for developing maximal strength (10,17). Yet, with the significant increases in strength and power, the data show no incompatibility was observed in this composite total conditioning program. In addition, our results were similar to Volpe et al. (29), who showed that a 3 $d \cdot wk^{-1}$ program of this type had no impact on strength development while improving cardiovascular function. It appears that much higher intensities and frequencies of aerobic exercise training would be needed to elicit an incompatibility phenomenon, thought by some to be the symptom of acute overtraining (17).

The effects of endurance training were evident in the upper-body-only training groups. We observed reductions in CSA in the vastus intermedius and semimembranosus muscles whereas total thigh CSA did not change. Previous studies have shown that endurance training may ultimately degrade myofibrillar protein to optimize oxygen uptake kinetics (13). In fact, we have previously shown significant reductions in muscle fiber area of Type I fibers after 12 wk of high-intensity endurance training in men (17). The inclusion of resistance training may offset any potential atrophy as significant hypertrophy was observed in both total-body training groups. Therefore, the present study and our previous work (15,17) indicate it is possible to increase muscle CSA when aerobic and resistance training are performed concurrently.

Muscular strength is one of the important outcome variables reflecting the underlying adaptations in the neuromuscular system. Significant increases in 1 RM bench press were observed for all groups from T1 to T2, T2 to T3, and T1 to T3, whereas only the total-body training groups significantly increased 1 RM squat at the same time points. For the 1 RM bench press, the TP and UP groups showed the greatest absolute improvements (34 vs 28%, respectively). This may have occurred because heavier resistances were used by the TP and UP groups in comparison with the TH and UH groups. It has been shown previously that loads corresponding to 5–6 RM may be most specific to increasing maximal strength (1). Thus, the higher loading may have contributed to the greater strength increases observed in the strength/power groups.

Longitudinally, similar increases in bench press performance have been reported over 15 (9), 20 (4), and 24 wk (19) in previously untrained women. However, unique to this study was the greater improvement observed between T2 and T3. Chilibeck et al. (4) reported an 8% increase in 1 RM bench press between 10 and 20 wk of resistance training. Herrick and Stone (9) reported a 5% increase in 1 RM bench press between weeks 12 and 15 of a 15-wk periodized program, whereas no change was observed from week 12 to 15 of training using a program with limited training variation. Collectively, these data indicate neuromuscular adaptations to resistance training occur at a much slower rate after an initial period, particularly when there is minimal program variation. The mean increase of all the training groups in the present study was approximately 12% between T2 and T3. This period coincided with performance of the second 12-wk training cycle. Therefore, the results of the present study indicate the importance of periodized resistance training for continued long-term increases in upper-body strength and indicate that the underlying changes in muscle hypertrophy help mediate such adaptations.

Only the total-body training groups significantly increased 1 RM squat in the present study. A 38% increase was observed in the TP group and a 34% increase was observed in the TH group showed that both groups periodizing loading to heavier ranges saw improvements. The lack of a training effect in the squat for the upper-body-only training groups was not surprising based on the principle of training specificity. We have previously reported limited lower-body strength and power improvements in men who only performed upper-body resistance training (17). Interestingly, a trend for improvement ($P = 0.08$ and 0.10 for the UP and UH groups, respectively) was observed in the upper-body groups from T1 to T3. This may have been due to the greater size and strength of upper-body and trunk stabilizing muscles involved in the performance of the squat exercise technique. For example, trunk exercises (e.g., back extension, incline sit-up) were routinely performed, and increases in training loads were observed for these exercises, indicating muscular strength increases. Therefore, the ability of the upper body to tolerate greater stress and support increased loads that the lower-body musculature was already capable of supporting in the squat exercise may have contributed to these trends for improvement. Although most strength gains are specific to the training stimulus, carryover of strength has been observed (especially in individuals with limited training experience), and this likely occurred in the present study. Nevertheless, this finding demonstrates the importance of upper-body strength training for stabilizing muscles involved in a whole-body movement.

Although muscular strength has been the focus of many investigations, power is often an overlooked component vital for physical performance. Lower-body power increased significantly only for the total-body groups between T1 and T3. In addition, a significant power improvement in jump squat power at 90% of 1 RM was observed at T2 compared with T1 only for the TP training group. Additionally, the largest absolute increases in jump squat power were observed in the TP group. Examining the training effects for upper-body power, it was observed that power increased at T2 compared with T1 only for the TP group but increased significantly at T3 compared with T1 in all training groups. In addition, the improvement in bench press power demonstrated by the TP group was significantly greater than all groups at T3. The protocol used in the TP was specifically designed to increase both strength and power by utilizing heavy loads for multiple-joint exercises. This type of training program has been shown to be effective for increasing muscular power (12,23,24). The significant improvements in lower-body power observed in the TH group demonstrate the contribution of the force component in the power equation. Consistent with our hypotheses related to specificity, increased jump squat power was not observed in either of the upper-body groups despite a small, nonsignificant increase in 1 RM squat previously discussed. These data highlight the importance of the principle of training specificity.

In summary, 6 months of periodized resistance training in the context of a total conditioning program in women was effective for increasing muscular hypertrophy, strength, and power for both loading ranges. However, the range of 3–8 RM loading range did appear to demonstrate a more systematic frequency of significant increases in more individual muscles over the entire training period. Both total body training programs were effective as "training gestalts" in stimulating significant improvements albeit the mediating mechanisms related to the combination of acute program variables (exercise choice, rest period lengths) created by each program were most likely different. To our knowledge, this investigation was the first comprehensive examination of muscle hypertrophy using different periodized resistance training programs in previously untrained women. Upper-body-only training was specific to upper-body changes as no significant changes were observed in total-body performance measurements or in thigh musculature hypertrophy. Perhaps the most critical finding of this investigation was the continued improvement in measures observed from 3 to 6 months as several previous investigations in women using programs with limited variation have shown plateaus occurring approximately after 12–15 wk of resistance training. Such findings may be of practical importance to women who participate in physically demanding jobs (i.e., such as the military, law enforcement, fire fighting, sports) and may benefit greatly from the associated increases in muscle strength, power, and hypertrophy observed during periodized resistance training.

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