Resistance weight training during caloric restriction enhances lean body weight maintenance[1-3]

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ABSTRACT To assess the individual and combined effects of weight loss and weight training on body weight and body composition, 40 obese women were randomly assigned to one of four groups for an 8 wk weight-loss study. These groups were control (C); diet without exercise (DO); diet plus weight training (DPE); and weight training without diet (EO). Body weight decreased for DO (−4.47 kg) and DPE (−3.89 kg) compared with C (−0.38 kg) and EO (0.45 kg). Lean body weight (LBW) increased for EO (1.07 kg) compared with DO (−0.91 kg) and C (−0.31 kg) and for DPE (0.43 kg) compared with DO. Upper-arm muscle areas (determined by radiograph) increased for DPE (11.2 cm^2) and EO (10.4 cm^2) compared with C (2.7 cm^2) and DO (2.1 cm^2). It was concluded that weight training results in comparable gains in muscle area and strength for DPE and EO. Adding weight training exercise to a caloric restriction program results in maintenance of LBW compared with DO. *Am J Clin Nutr* 1988;47:19–25.

KEY WORDS Weight loss, exercise, weight training, exertion, diet, lean body weight

Introduction

Weight loss induced by caloric restriction generally results in loss of both fat and lean body weight (LBW) with the percentage lost as LBW increasing relative to the severity of the caloric deficit (1). For example, losses of LBW expressed as a percent of total weight lost have ranged from as little as 15% for mild caloric restriction (2) to as high as 50–70% during semistarvation (3, 4).

Negative caloric balance induced by exercise or in combination with caloric restriction appears to minimize losses of LBW. Zuti and Golding (5), Weltman et al (6), Rath and Slabochova (7), and Buskirk et al (4) all reported maintenance of LBW with exercise compared with diet-only controls.

The above diet and exercise studies have used aerobic exercise, which by itself is not known to result in gains in LBW (8, 9). Resistance weight training, which has been shown to result in gains in LBW (10–12) has not been used to elicit maintenance and/or increases of LBW during dietary-induced weight loss. Moreover, while it has been demonstrated in animals that regional muscular hypertropy can occur during calorically induced weight loss and even starvation (13, 14), this has not been shown for humans.

The purpose of this research, therefore, was to investigate the effect of resistance weight training either alone or in combination with a calorically induced weight loss regimen on LBW.

Subjects and methods

Subjects

Forty obese female subjects (mean ± SEM, weight = 75.1 ± 1.1 kg, percent fat = 35.9 ± 0.9%, height = 166.4 ± 1.4 cm, age = 32.9 ± 1.5 y), after informed consent, volunteered to participate in an 8-wk weight-loss study. Subjects were recruited by advertisement in a local newspaper and personally interviewed before admission. After pretesting, the subjects were randomly assigned to one of four groups: *1*) control (C; no caloric restriction, no exercise), *2*) diet only (DO; caloric restriction, no exercise), *3*) diet plus exercise (DPE; caloric restriction, weight training exercise), and *4*) exercise only (EO; no caloric restriction, weight training exercise). There were no statistical differences between the groups for any of the pretest variables. The study was in accord with the policies of the University of Wisconsin-Madison Center for Health Sciences human subjects committee.

Dietary intervention

Baseline caloric requirements were estimated using body weight, height, age, sex, and activity level (15) and then reduced

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by 1000 kcal/d. The estimated baseline requirements were 2200–2500 kcal/d. The specific dietary protocol was a modification of the dietary exchange program of the American Diabetes Association (16) in which subjects choose foods from different categories. The nutritionally balanced diet consisted of 50% carbohydrate, 27% protein, and 23% fat and included a daily protein supplement. C and EO subjects were instructed to maintain their normal caloric intake.

Protein supplements were given to the two diet groups to ensure protein intake ≥ 1.0 g/kg body wt. The protein supplement, taken with 8 oz (0.24 L) nonfat milk, supplied 25 g/d of high-quality protein (60% of recommended dietary allowance [RDA]) and ~50% of the RDA for vitamins A, B-6, B12, C, D, and E and three minerals: calcium, iron, and phosphorus (17).

Subjects met weekly with a dietary counselor. Food diaries (recorded daily throughout the 8-wk intervention period for the DO and DPE groups) were evaluated for compliance, weight changes were recorded, and individual success strategies were developed. The dietary counselor attempted to induce the subjects to make permanent changes in their dietary lifestyles.

Exercise program

Subjects did resistance weight training, under supervision, 3 d/wk using a Universal eight station Power-Pac 200 Gym (Universal Gym, Cedar Rapids, IA). The weight training routine included the following exercises: bench press, inverse leg press, lateral pull down, biceps curl, triceps extension, calf raise, leg extension, and hamstring curl as described by Sprague and Reynolds (18). Ten repetitions were completed in the first two sets of each exercise and as many repetitions as the subject could perform were completed in the third set. The exercise supervisor and the subject's partner provided strong verbal encouragement during the final phase of the third set. The subject's partner helped lift the weight past any momentary weak points in the final set until the subject was unable to voluntarily complete another repetition. Resistance was increased when 12 or more repetitions could be completed in the third set. Individual exercise logs were maintained by the exercise supervisor and included the subject's daily training weight and repetitions completed per set. Other forms of exercise for the DPE and EO groups were actively discouraged. The C and DO subjects agreed not to exercise for the duration of the program.

Body composition

Body weight was measured to within 50 g using a Homms beam balance (Western, San Francisco, CA). Body density was determined using hydrostatic weighing with a residual-lung-volume correction. Ten to twelve repeat weighings were taken with the last five trials averaged and used as the true underwater weight (19). Residual-lung-volume measurements were made out of the water with the nitrogen washout technique with the subject in the same bend-over seated position as used in the underwater weighing (20). The average of three repeat determinations was used as the criterion score. Percent body fat was calculated from body density using the Siri equation (21). Fat weight was determined by multiplying percent fat times body weight and LBW was determined by subtracting fat weight from body weight.

Right upper-arm radiographs were taken as described by Katch and Behnke (22). A 2 ms exposure at 1 kV was used with the instrument head 183 cm from the film. An arm stand individually adjusted for height was used to ensure that the arm was placed in the same horizontal position pre- and posttest.

To analyze the radiographs, an individual overlay template was constructed for each subject on which a longitudinal line was drawn through the centers of the distal and proximal humeral heads. Perpendicular lines were constructed 10% and 80% of the longitudinal length from the distal edge of the humerus. Fat, muscle, and bone could be discerned as separate distinct radiograph shadows. The fat and muscle-bone areas of the upper arm bounded by the perpendicular lines were determined using a Keuffel and Esser planimeter (Keuffel & Esser Co, Parsippany, NJ). Muscle and bone areas were not separated. This reduced the potential of measurement error. Because bone area does not change, any changes in the muscle and bone areas reflect muscle changes. Each area score represents an average of three tracings. All radiographs were numbered and analyzed without knowledge of subject's identity.

Duplicate radiograph measurements (separated by 10 min) were done on five subjects. The test-retest reliability for determining the total arm area and muscle-bone area for the duplicate radiograph measurements are $r = 0.96$ and $r = 0.98$, respectively, with a SEE of 7.6 cm^2 and 3.4 cm^2, respectively. Reliability of the radiograph analysis was tested by retracing the areas for 10 subjects after removal and replacement of the tracing template. A reliability of $r = 0.99$ with a SEE of 3.3 cm^2 for muscle-bone area and $r = 0.96$ and a SEE of 7.6 cm^2 for total arm area was found.

Anthropometrics

Five skinfold (SF) measurements (subscapulae, triceps, iliac, abdominal, and thigh) and five girth measurements (abdominal, biceps flexed, forearm, thigh, and calf) were taken as described by Behnke and Wilmore (23). The same investigator made all pre- and posttest measurements in duplicate.

Strength

A one-repetition bench press maximum test (1-rep max) was performed. Subjects lifted increasingly heavier weights until reaching a weight they were unable to raise. Subjects were given strong verbal encouragement. After a 5-min rest, the subjects again tried the failed weight. The last successfully lifted weight was taken as the 1-rep max.

Energy cost of weight training

The caloric expenditure of the weight training program was determined using five subjects. The protocol consisted of a 5-min rest period, an exercise routine (~42 min), and a 5-min recovery period. Exercise consisted of the same weight-training routine used by the individual during the study. The exercise caloric cost was estimated by multiplying oxygen uptake ($\dot{V}O_2$) by the kcal/L O_2 associated with the respiratory exchange ratio (RER) of the expired gases (24). An Applied Electrochemistry S3A oxygen analyzer (Ametek, Pittsburgh, PA), Beckman LB2 Medical Gas Analyzer (Beckman Instruments, Inc, Lincoln-Wood, IL), and a Validyne Model MC1 transducer amplifier (Validyne, Northridge, CA) connected to a Hans Rudolph model 3800 pneumotachograph (Hans Rudolph Inc, Kansas City, MO) were used to measure $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), and ventilation ($\dot{V}_E$), respectively. This equipment was interfaced with an Apple IIE computer (Apple, Cupertino, CA), which averaged and reported scores per minute.

Statistical analyses

Differences between groups for all dependent variables were analyzed using one-way analysis of variance on the posttest minus pretest scores. This analysis yields similar results to a 2 × 4 ANOVA. The level of statistical significance was set at $p < 0.05$.

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TABLE 1
Changes in upper-arm muscle and fat areas as determined by radiograph measurements (mean ± SEM)

Variable	Group*	Pretest	Posttest	Posttest − pretest	Posttest − pretest $p < 0.05$
Arm area (cm^2)†	C	251.27 ± 6.69	253.27 ± 6.58	2.00 ± 1.55	C, EO > DO
	DO	254.96 ± 9.75	250.17 ± 10.12	−4.79 ± 1.53	
	DPE	262.29 ± 6.01	262.92 ± 5.61	0.63 ± 1.60	
	EO	255.67 ± 10.26	261.75 ± 11.06	6.08 ± 1.21	
Muscle and bone area (cm^2)	C	180.17 ± 5.34	182.86 ± 4.83	2.69 ± 1.80	DPE > C, DO
	DO	170.45 ± 4.12	172.55 ± 4.79	2.10 ± 1.25	EO > C, DO
	DPE	175.82 ± 3.52	187.05 ± 3.53	11.23 ± 1.72	
	EO	173.84 ± 6.87	184.28 ± 7.33	10.44 ± 2.02	
Fat area (cm^2)‡	C	71.10 ± 3.04	70.41 ± 3.19	−0.69 ± 0.89	DPE > C
	DO	84.51 ± 6.34	77.62 ± 6.51	−6.89 ± 1.54	
	DPE	86.47 ± 5.28	75.87 ± 4.32	−10.60 ± 1.87	
	EO	81.83 ± 7.48	77.47 ± 7.44	−4.36 ± 1.77	

* C = control, DO = diet only, DPE = diet plus exercise, and EO = exercise only.
† Arm area = fat + muscle + bone areas.
‡ Fat area = arm area − muscle and bone areas.

A Scheffe' posthoc test was employed to analyze specific mean comparisons ($p = 0.05$). Pearson r was computed using the replicate measures for the radiograph and anthropometric data to determine reliability of individual differences. All scores are reported as the mean ± SEM.

Results

Compliance

None of the subjects missed any scheduled diet counseling meetings. Exercising subjects missed a total of 22 of a possible 495 exercise sessions resulting in a 95% compliance. None of the exercising subjects incurred any injuries that precluded participation in any of the training sessions. A few of the subjects reported mild muscular soreness initially with the soreness disappearing by the end of the second week. Two of the original DO subjects were dropped from the study: one for surgery and the other for a death in the family.

Radiograph analyses

Changes in the arm areas are presented in **Table 1** and are graphically shown in **Figure 1.** The changes in total-arm-area (fat and muscle-bone) range from a 6.08 cm^2 (2.4%) increase for the EO group to a −4.79 cm^2 (−1.9%) decrease for the DO group. The C and EO group changes are statistically more positive than the DO group changes. Analysis of the muscle-bone area changes show that the DPE and EO groups significantly increase upper-arm muscle area by 11.23 cm^2 (6.4%) and 10.44 cm^2 (6.0%), respectively, compared with the C and DO groups (Table 1). Fat area changes (total arm area minus muscle-bone area) range from −0.69 cm^2 (1.0%) for the C group to −10.60 cm^2 (12.3%) for the DPE group. The DPE group significantly reduced its mean fat area compared with C.

Fat losses account for the total-arm-area decreases for the DO group whereas there is an increase in muscle area and a concomitant decrease in fat area for both the EO and DPE groups. These data indicate that diet and exercise act independently on the upper-arm fat and muscle areas.

Strength changes

Table 2 presents strength changes in the 1-rep max bench press. There are no differences between the DPE (5.31 kg) and EO (4.77 kg) groups in the pre- to posttest increase. Both the DPE and EO groups exhibited significant increases in 1-rep max compared with the C and DO groups.

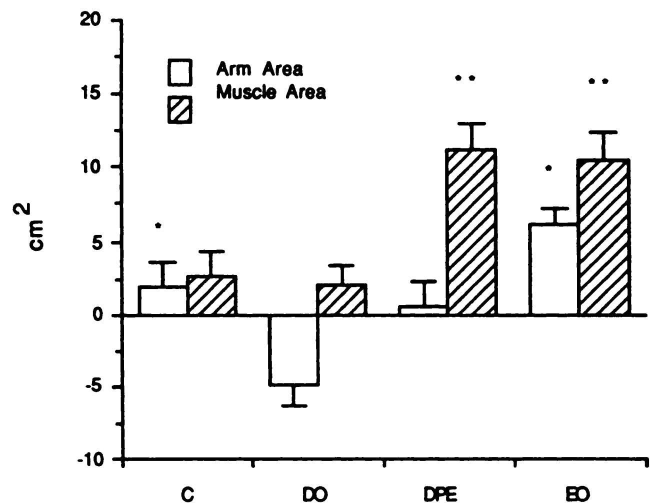

FIG 1. Arm and muscle area changes as a result of the interventions. Changes are expressed as posttest minus pretest. C = control, DO = diet only, DPE = diet plus exercise, and EO = exercise only. Mean change ± SEM. *DO < C, EO; **DO, C < DPE, EO; $p < 0.05$.

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TABLE 2
Bench press one-repetition maximum strength changes (mean ± SEM)

Variable	Group*	Pretest	Posttest	Posttest − pretest	Posttest − pretest $p < 0.05$
Bench press (kg)	C	32.39 ± 2.18	33.52 ± 2.22	1.13 ± 0.43	DPE > C, DO
	DO	32.05 ± 1.60	31.36 ± 1.85	−0.69 ± 0.59	EO > C, DO
	DPE	29.92 ± 1.21	35.23 ± 1.67	5.31 ± 0.90	
	EO	35.00 ± 2.10	39.77 ± 2.59	4.77 ± 0.73	

* C = control, DO = diet only, DPE =diet plus exercise, and EO = exercise only.

Anthropometric changes

Table 3 presents the anthropometric data. Changes in the biceps flexed girth range from a −0.98 cm (−3.0%) decrease for the DO group to a 1.6 cm (4.9%) increase for the EO group. The DO group biceps flexed girth significantly decreased compared with the C and DPE groups whereas the EO group change is statistically larger than the C, DO, and DPE groups. Collectively, these anthropometric data indicate increases in muscle related variables (LBW and biceps flexed girth) for both exercise groups (supported by radiograph data) and decreases in fat-related variables (body weight, fat weight, percent fat, sum of five skinfold measurements, and thigh and abdomen circumference) for the DO, DPE, and EO groups.

Body composition changes

Body composition changes are found in **Table 4** and **Figure 2.** The weight changes range from a slight (< 1%) increase for the EO group to a 5.9% (−4.47 kg) decrease for the DO group. The DO and DPE groups significantly lost weight compared with the C and EO groups. There is no statistical difference in weight loss between the DO and DPE groups. Thus, adding weight training did not increase the rate of weight loss for the DPE group.

The LBW changes are particularly revealing and noteworthy. LBW changes range from a 0.92 kg (−1.9%) decrease for the DO group to a 1.07 kg (2.2%) increase for the EO group. The EO and DPE groups significantly increased LBW compared with the DO group. Moreover, the EO group changes are also significantly larger than the C group changes.

Fat weight changes range from no change for the C group to a 14.4% (−4.32 kg) decrease for the DPE group. The DO and DPE group's fat weight losses, although not different from each other, are statistically different from the C and EO groups.

Physiological demands of weight training

It is of importance from an energy balance standpoint to estimate the caloric requirement of the weight training

TABLE 3
Anthropometric changes (mean ± SEM)

Variable	Group*	Pretest	Posttest	Posttest − pretest	Posttest − pretest $p < 0.05$
Abdomen (cm)	C	78.04 ± 1.93	78.42 ± 2.22	0.38 ± 0.46	C, EO > DPE
	DO	82.90 ± 2.76	79.75 ± 2.85	−3.15 ± 0.53	
	DPE	84.60 ± 1.34	80.64 ± 1.30	−3.96 ± 1.12	
	EO	80.51 ± 2.54	81.13 ± 2.75	0.62 ± 0.63	
Thigh (cm)	C	65.64 ± 1.49	65.71 ± 1.48	0.07 ± 0.39	C > DPE
	DO	64.12 ± 0.98	63.21 ± 1.08	−0.91 ± 0.46	EO > DPE
	DPE	66.65 ± 0.89	65.04 ± 0.89	−1.61 ± 0.40	
	EO	64.41 ± 1.36	65.42 ± 1.24	1.01 ± 0.32	
Biceps flexed (cm)	C	32.29 ± 0.75	32.71 ± 0.84	0.42 ± 0.17	C, DPE > DO
	DO	32.89 ± 0.88	31.91 ± 0.83	−0.98 ± 0.29	EO > C, DO, DPE
	DPE	33.31 ± 0.62	33.48 ± 0.59	0.17 ± 0.19	
	EO	32.79 ± 1.29	34.39 ± 1.24	1.60 ± 0.16	
Sum five skinfolds measurements (mm)	C	162.06 ± 7.89	158.47 ± 9.57	−3.59 ± 3.64	C > DO, DPE
	DO	179.58 ± 10.52	151.26 ± 11.73	−28.32 ± 5.15	EO > DO, DPE
	DPE	191.06 ± 11.29	167.38 ± 10.20	−23.68 ± 3.17	
	EO	170.07 ± 11.57	170.57 ± 12.73	−0.50 ± 5.03	

* C = control, DO = diet only, DPE = diet plus exercise, and EO = exercise only.

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TABLE 4
Body composition changes (mean ± SEM)

Variable	Group*	Pretest	Posttest	Posttest − pretest	Posttest − pretest $p < 0.05$
Weight (kg)	C	72.70 ± 1.87	72.32 ± 2.40	−0.38 ± 0.65	C > DO, DPE
	DO	75.19 ± 2.49	70.72 ± 2.46	−4.47 ± 0.45	EO > DO, DPE
	DPE	77.53 ± 1.77	73.64 ± 1.83	−3.89 ± 0.32	
	EO	73.89 ± 3.29	74.34 ± 3.59	0.45 ± 0.64	
Lean body weight (kg)	C	48.55 ± 0.79	48.24 ± 1.11	−0.31 ± 0.46	EO > C
	DO	47.73 ± 1.21	46.82 ± 1.12	−0.91 ± 0.28	EO, DPE > DO
	DPE	47.62 ± 1.31	48.05 ± 1.27	0.43 ± 0.26	
	EO	47.71 ± 1.79	48.78 ± 1.79	1.07 ± 0.25	
Fat weight (kg)	C	24.15 ± 3.84	24.08 ± 1.51	−0.07 ± 0.37	EO > DO, DPE
	DO	27.46 ± 1.82	23.90 ± 1.94	−3.56 ± 0.37	C > DO, DPE
	DPE	29.91 ± 2.06	25.59 ± 1.90	−4.32 ± 0.38	
	EO	26.18 ± 2.35	25.56 ± 2.65	−0.62 ± 0.52	
Percent fat	C	33.07 ± 1.12	33.10 ± 1.09	0.03 ± 0.39	C > DO, DPE
	DO	36.27 ± 1.41	33.44 ± 1.71	−2.83 ± 0.46	EO > DPE
	DPE	38.31 ± 2.02	34.46 ± 1.97	−3.85 ± 0.35	
	EO	35.06 ± 1.79	33.85 ± 2.16	−1.21 ± 0.41	

* C = control, DO = diet only, DPE = diet plus exercise, and EO = exercise only.

exercises used in this study. **Table 5** presents data for five subjects. As can be seen, weight training elicits an average total $\dot{V}O_2$ of 36.3 ± 1.4 L (mean ± SEM) during the 42 min, eight-station weight training workout. Fifth minute recovery values for $\dot{V}O_2$ and RER of 0.39 ± 0.02 L/min and 0.84 ± 0.30, respectively, are near resting values. Thus, the net caloric expenditure (total during exercise and recovery − resting baseline) is a modest 139.2 ± 7.9 kcal (1 L O_2 = 5.05 kcal was used since the average RER exceeded 1.0).

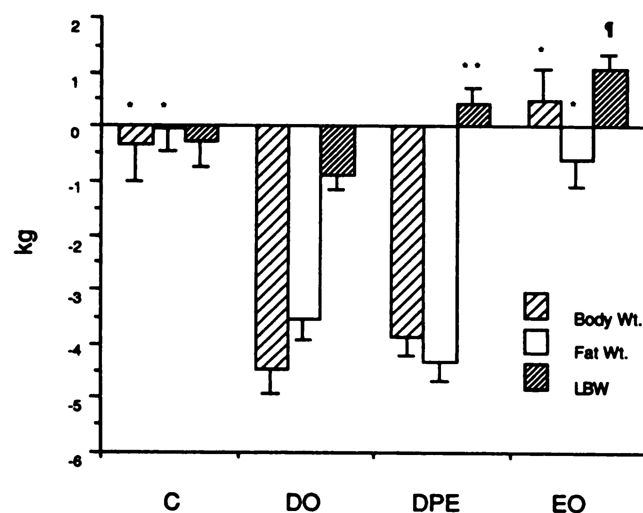

FIG 2. Body composition changes as a result of diet and exercise intervention. Changes are expressed as posttest minus pretest. LBW = lean body wt, C = control, DO = diet only, DPE = diet plus exercise, and EO = exercise only. Mean change ± SEM. *DO, DPE < C, EO; **DO < DPE; ¶ C, DO < EO; $p < 0.05$.

Table 6 summarizes the treatment effects of caloric restriction and weight training for the different dependent variables. Because there is no diet-by-exercise interaction, it can be concluded that caloric restriction and weight training act independently during weight loss. The diet treatment has a statistically significant effect on variables having a fat component but there is no diet effect on muscle area, strength, or LBW. The exercise treatment has statistically significant effects on variables with muscle components.

Discussion

The increase in arm muscle area brought about by weight training (Table 1) is evidence that muscle hyper-

TABLE 5
Physiological demands of resistance weight training for five subjects (mean ± SEM)

Variable*	Measurement
Body weight (kg)	74.30 ± 2.73
RER rest	0.88 ± 0.04
RER exercise	1.03 ± 0.001
$\dot{V}O_2$ rest (L/min)	0.23 ± 0.01
$\dot{V}O_2$ exercise (L)	36.30 ± 1.37
$\dot{V}O_2$ recovery (L)	2.21 ± 0.01
$\dot{V}O_2$ net† (L)	27.59 ± 1.56
Kcal net†	139.20 ± 7.87

* RER = respiratory exchange ratio. $\dot{V}O_2$ = oxygen uptake.
† Net = exercise (42 min + recovery [5 min]) − rest (baseline scores, × 47 min).

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TABLE 6
Main effects for diet and exercise

Variable	Diet effect*	Exercise effect*	Interactions*
Upper-arm area			
Fat, muscle and bone	decrease	increase	NS
Upper-arm area			
Muscle and bone	NS	increase	NS
Upper-arm area			
Fat area	decrease	NS	NS
Bench press			
1-Rep max†	NS	increase	NS
Abdomen circumference	decrease	NS	NS
Thigh circumference	decrease	NS	NS
Calf circumference	decrease	NS	NS
Forearm circumference	NS	NS	NS
Flexed biceps circumference	decrease	increase	NS
Sum five skinfolds measurements	decrease	NS	NS
Weight	decrease	NS	NS
Lean body weight	NS	increase	NS
Fat weight	decrease	NS	NS
Percent fat	decrease	decrease	NS

* Treatment effect caused variable to increase or decrease, $p < 0.05$.
† 1-Rep max = one-repetition bench press maximum test.

trophy can occur during caloric restriction and consequent weight loss. Although related data in the literature using computer-assisted tomography confirm the existence of weight training-induced muscle hypertrophy (25), the present data appear to be the first to demonstrate muscular hypertrophy (by direct measurement) with accompanying weight loss in humans.

The present radiograph data show increases in upper-arm muscle area for both the DPE and EO groups with concomitant increases in specific muscular strength (Tables 1 and 2) and support the finding that muscle cross-sectional areas and absolute strengths are directly correlated (26). The training records of the exercising subjects reflected increases in weekly training weights throughout the study for all of the exercises. This is suggestive of muscle hypertrophy throughout the body (26). The increases in total LBW support this possibility.

An important finding of this study is the lack of interaction between the diet and exercise treatments (Table 6). The data suggest that the order of presentation of the treatments would not greatly affect the end result. For example, one could reduce caloric intake for 8 wk and then resistance weight train for 8 wk and obtain the same results as found by dieting and exercising concurrently. Support for this position can be found in Tables 1, 3, and 4 where, in most cases, adding the DO and EO group changes yields a result very similar to the DPE group changes.

The lack of a diet treatment effect on arm muscle area (Table 1) and strength (Table 2) is surprising. Apparently, with mild caloric restriction an adequate environment for muscle growth can exist. The protein supplement helped ensure sufficient protein intake to allow muscle growth to occur.

It is important to note that simply using the girth data without the radiograph information would give very misleading results relative to muscle hypertrophy. Girth changes can include fat and/or muscle. The exercise effect on muscle growth during caloric restriction may be masked by fat-pad changes. That is, if there is a fat area decrease with a concomitant muscle area increase, the net change could be zero if measured by girths alone. An example of this can be found by examining the biceps girth data in Table 3 and the radiograph data in Table 1. Although there is only a modest 0.5% increase in biceps girth for the DPE group, the radiograph data show a 6% increase in muscle area. Thus, it must be concluded that errors in estimation of muscle hypertrophy may occur when using only girth measurements.

The increase of 0.43 kg in LBW for the DPE group is comparable to the largest increases reported in other diet-plus-exercise studies. Zuti and Golding (5) and Lewis et al (27) report LBW increases of 0.5 and 1.1 kg over 16 and 17 wk, respectively. This is in contrast to most diet-plus-exercise studies that report losses of LBW even with the addition of exercise (4, 6, 28, 29).

Although maintenance of LBW may result from adding either aerobic (Zuti and Golding [5] Lewis et al [27]) or resistance weight training exercise to caloric restriction, the mechanism for maintenance may be quite different. Assuming adequate protein intake (1.0 g/kg body wt), maintenance of LBW may result from increasing the proportion of calories expended as fat and reducing the need to deaminate amino acids to supply carbohydrates or through muscle use. Although it is possible that aerobic exercise results in maintenance of LBW through muscle use, it is more likely to be a result of increased fat usage because aerobic exercise is not known to result in muscle hypertrophy (9). In contrast, because weight training elicits a moderate caloric expenditure with an emphasis on carbohydrates as a fuel, the increase in regional muscle area and total body LBW almost certainly does not result from increased caloric expenditure and fat use. Rather, with weight training increases in muscle area and maintenance of LBW are most likely a result of muscle overload training.

Finally, that the DO group lost LBW but did not correspondingly decrease strength or radiograph muscle area is perplexing and difficult to explain. One would have expected that with losses in LBW there would be changes in muscle area and strength. Perhaps there are moderate lean-tissue losses throughout the body and these losses are from the nonmuscle protein pool of the body.

In conclusion, data from this study indicate that weight training added to a caloric restriction program results in maintenance of LBW and regional increases in muscle area. When diet plus weight-training exercise is compared with exercise without caloric restriction, there is no difference in the rate of strength gain or magnitude of upper-

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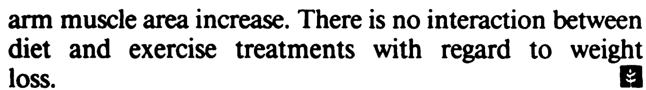
arm muscle area increase. There is no interaction between diet and exercise treatments with regard to weight loss.

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