

Body Composition and Strength Changes in Women with Milk and Resistance Exercise

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ABSTRACT

JOSSE, A. R., J. E. TANG, M. A. TARNOPOLSKY, and S. M. PHILLIPS. Body Composition and Strength Changes in Women with Milk and Resistance Exercise. *Med. Sci. Sports Exerc.*, Vol. 42, No. 6, pp. 1122–1130, 2010. **Purpose:** We aimed to determine whether women consuming fat-free milk versus isoenergetic carbohydrate after resistance exercise would see augmented gains in lean mass and reductions in fat mass similar to what we observed in young men. **Methods:** Young women were randomized to drink either fat-free milk (MILK: $n = 10$; age (mean \pm SD) = 23.2 \pm 2.8 yr; BMI = 26.2 \pm 4.2 kg·m⁻²) or isoenergetic carbohydrate (CON: $n = 10$; age = 22.4 \pm 2.4 yr; BMI = 25.2 \pm 3.8 kg·m⁻²) immediately after and 1 h after exercise (2 \times 500 mL). Subjects exercised 5 d·wk⁻¹ for 12 wk. Body composition changes were measured by dual-energy x-ray absorptiometry, and subjects' strength and fasting blood were measured before and after training. **Results:** CON gained weight after training (CON: +0.86 \pm 0.4 kg, $P < 0.05$; MILK: +0.50 \pm 0.4 kg, $P = 0.29$). Lean mass increased with training in both groups ($P < 0.01$), with a greater net gain in MILK versus CON (1.9 \pm 0.2 vs 1.1 \pm 0.2 kg, respectively, $P < 0.01$). Fat mass decreased with training in MILK only (-1.6 \pm 0.4 kg, $P < 0.01$; CON: -0.3 \pm 0.3 kg, $P = 0.41$). Isotonic strength increased more in MILK than CON ($P < 0.05$) for some exercises. Serum 25-hydroxyvitamin D increased in both groups but to a greater extent in MILK than CON (+6.5 \pm 1.1 vs +2.8 \pm 1.3 nM, respectively, $P < 0.05$), and parathyroid hormone decreased only in MILK (-1.2 \pm 0.2 pM, $P < 0.01$). **Conclusions:** Heavy, whole-body resistance exercise with the consumption of milk versus carbohydrate in the early postexercise period resulted in greater muscle mass accretion, strength gains, fat mass loss, and a possible reduction in bone turnover in women after 12 wk. Our results, similar to those in men, highlight that milk is an effective drink to support favorable body composition changes in women with resistance training. **Key Words:** DAIRY PROTEIN, HYPERTROPHY, BONE HEALTH, HORMONE

Resistance exercise is a potent stimulus to increase muscle protein synthesis and to stimulate positive net protein balance (2,25,29). If resistance exercise is performed chronically (i.e., resistance training), then successive bouts of positive protein balance are thought to summate yielding hypertrophy over time (15,38). To maximize hypertrophic potential of resistance exercise, it appears that consumption of high-quality protein in close temporal proximity after resistance exercise can augment muscle protein synthesis (10) and also enhances resistance training-induced increases in muscle mass (9,15,20). Thus, combining consumption of high-quality protein with resistance exercise (1,24), in particular of milk-based proteins, has been shown

to enhance gains in muscle mass in young healthy untrained men (15,38).

Resistance training-induced muscle hypertrophy in men is thought by some to be facilitated in part by their hormonal response to resistance exercise (22a). In men, resistance exercise elicits higher acute circulating testosterone levels than women, which has been thought to enhance anabolism (21,22a). This “hormonal hypothesis” of strength and muscle mass gain seems plausible, and yet several studies undertaken in women and men have shown that this may not necessarily be the case (4,5,21,30–32, 36a). Women engaging in resistance training for as little as 6 wk show comparable relative gains in strength and lean tissue mass as those seen in men (31). Apart from these studies (4,5,21,30–32), we remain largely ignorant of the longer-term potential for a greater training response in women when both exercise and feeding are simultaneously manipulated.

Resistance training is not a common exercise modality of choice in young women; however, the health benefits they stand to gain from this form of exercise in terms of improving physical strength and muscular, metabolic, and in particular bone health cannot be achieved by other means (4,6,7,26,39). Moreover, despite data showing that milk adequately supports gains in muscle mass and loss of fat mass in men (15,38), generally, young women continue to

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avoid consuming dairy products (3,27), with the primary stated reason being that dairy foods are fattening (12,13).

We aimed to test the hypothesis of whether young healthy women will increase muscle mass and lose fat mass after undergoing 12 wk of intense resistance training, a protocol that has been used previously in our laboratory in men (15). We also hypothesized that strength gains and lean muscle mass accretion would be greater after the consumption of fat-free fluid milk versus an isoenergetic 9% carbohydrate (maltodextrin) drink. A final aim of our study was to determine the effect of consuming an extra 1 L of fat-free milk on the training days during the 12 wk on serum vitamin D (25-hydroxyvitamin D (25[OH]D)), parathyroid hormone (PTH) levels, and markers of bone turnover. We hypothesized that milk consumption would favorably affect these parameters and thereby possibly promote bone health.

METHODS

Participants. Young, healthy women were recruited from the McMaster University student population and the surrounding Hamilton area. All participants were screened before inclusion for standard medical conditions that would preclude their participation in the trial. Subjects were deemed healthy on the basis of their responses to the medical screening questionnaire and thus were eligible to participate. In terms of exercise frequency before the study, subjects were not sedentary but were recreationally active with respect to aerobic exercise (no more than two to three times a week). However, subjects could not be participating in any resistance exercise activities for at least 8 months before the study. Subjects were excluded from participating in the study if they were clinically diagnosed with lactose intolerance or had any history of a milk protein allergy. Women who consumed any dietary supplements (e.g., vitamins, minerals, protein supplements) in the last 8 months before study commencement were also excluded. In addition, subjects all reported having a regular menstrual cycle. Equivalent numbers of women ($n = 5$ per group) were taking oral contraceptives. Once all inclusion criteria were met, the risks associated with the study protocol were explained to the subjects, and informed consent was obtained. The protocol was approved by the Research Ethics Board at McMaster University and Hamilton Health Sciences and conformed to all standards of Canada's Inter-agency Panel on Research Ethics for conducting human research (<http://www.pre.ethics.gc.ca/english/index.cfm>).

Protocol. The study was conducted over 12 wk. Subjects reported to the exercise training and testing center in the Exercise Metabolism Research Group laboratory in the Department of Kinesiology at McMaster University 5 d·wk⁻¹ for resistance training, which consisted of a rotating, whole-body, bilateral, split routine (see Training regimen section). Every day, 2 h before exercise training, subjects were required to refrain from eating or drinking

anything except water. Twenty subjects were randomly assigned to two groups: milk group (MILK) or control group (CON), with $n = 10$ in each. The postexercise nutritional provision, given in a single-blind fashion, was the only difference between these two groups. Subjects were asked to consume either 500 mL of fat-free (skimmed) white milk (160 kcal; 670 kJ; 18 g of protein, 24 g of carbohydrate, 0 g of fat) on two occasions (immediately and 1 h after exercise) daily (totaling 1 L of milk per day) or 500 mL of a control drink two times daily (1 L of isoenergetic maltodextrin drink as a 9% solution). The two drinks looked identical and were served to the participants in opaque containers. The drinks were also flavored with vanilla to ensure identical odor and taste. Subjects consumed one drink immediately after resistance exercise on a given day under the supervision of the study coordinators and were given the other drink to take with them and consume 1 h after exercise. No structured resistance exercise was carried out on the weekends, and no drinks were provided on those days. Outside of the drinks, subjects were instructed to maintain their usual dietary patterns, which were verified using 3-d food records.

Training regimen. The resistance training regimen in the present study was identical with that used in Hartman et al. (15). Please refer to this study for a more detailed description of the protocol. Briefly, the training regimen consisted of three different types of exercises performed on a rotating basis: pushing exercises (military press, bench press, and chest fly), pulling exercises (triceps push down, seated lateral pull down, seated row, seated bicep preacher curl, and abdominal exercises without weights), and leg exercises (45° incline leg press, seated two-leg knee extension, seated two-leg hamstring curl, and seated calf raise). Training was monitored daily one on one by personal trainers or trained study personnel to ensure proper exercise technique was used to avoid injury (i.e., good lifting form, proper rest intervals) and to adjust the weight lifted accordingly as subjects became stronger. Exercises were performed on guided motion machines (Nautilus, Tulsa, OK) at 80% of the subject's voluntary single repetition maximum (1RM) strength until after week 10 and then at 90% for weeks 11 and 12. In the first 2 wk, to allow the subject to become more comfortable and familiar with the equipment, two sets of 10–12 repetitions of each exercise were performed with a 2-min rest between sets. The training regimen was as follows: weeks 3–5, three sets of 10–12 repetitions; weeks 4–7, four sets of 8–10 repetitions; weeks 8–10, four sets of 6–8 repetitions; and weeks 11–12, four sets of 4–6 repetitions. Also, for weeks 3–12, subjects performed the last set of a given exercise to voluntary failure. Testing for subjects' 1RM was carried out four times during the study to adjust the weight lifted accordingly and to account for strength gains throughout the protocol (see Strength testing section).

Strength testing. Testing subjects' 1RM followed the same protocol as detailed in Hartman et al. (15). Testing for

each exercise took place every 4 wk. A 1RM determination was deemed successful if the subject was able to perform a full unassisted movement of the weight through the entire range of motion in a controlled manner (i.e., one repetition). The 1RM was determined within three tries, and subjects were allowed 3 min of rest between attempts to avoid fatigue. The prestudy 1RM was subsequently verified a few days later by asking the subject to return to the laboratory and to perform only one repetition at the designated weight. If need be, a third trial for 1RM was undertaken.

Dietary analysis. Before the commencement of the study and at weeks 6 and 12, subjects completed the 3-d diet records. Daily macronutrient intakes were assessed to help ensure that consumption did not drastically differ during the study. All dietary data were analyzed using Nutritionist 5[®] data analysis software (First Data Bank, San Bruno, CA).

Dual-energy x-ray absorptiometry (DXA) scan. At weeks 0 and 12, subjects underwent whole-body DXA scans (QDR-4500A; Hologic Inc., Waltham, MA) at the McMaster University Medical Centre to determine body composition changes (bone mass, fat mass, and muscle mass). All scans were performed by the same investigator. Study participants were scanned at the same time of day before and after wearing a standard hospital gown and were asked to consume the same meals and to follow a similar daily routine (i.e., controlling activity levels) for the day leading up to the postscan as they did for the prescan. As per protocol, the DXA machine underwent quality control testing daily to ensure no significant deviations existed in the day-to-day variability.

Blood sampling. On two occasions (preintervention and postintervention), participants were asked to come in to the laboratory for a routine fasting blood sample. Subjects were instructed to fast overnight for 10–12 h and to not consume anything else but water during that time. Blood was collected (~20 mL) into untreated tubes for serum and heparinized tubes for plasma, which were subsequently processed and stored in -20°C freezers for later analysis. Upon study completion, serum samples were sent to the Core Laboratory at the McMaster University Medical Centre for analysis of 25-hydroxyvitamin D (25[OH]D) and parathyroid hormone (PTH). Markers of bone turnover, osteocalcin, bone-specific alkaline phosphatase (BSAP), and carboxy terminal collagen cross-links (c-telopeptides (CTX)), were analyzed using commercially available enzyme-linked immunosorbent assay kits from Sigma Aldrich (St. Louis, MO) for osteocalcin and from Immunodiagnostic systems (Fountain Hills, AZ) for BSAP and CTX, respectively. We elected to measure the bone turnover biomarkers, OC, BSAP, and CTX, to better understand how bone metabolism in women is affected after intense resistance training and milk consumption. Lifting weights puts a stress on the bone to promote positive remodeling, and milk contains other vitamins and minerals (including vitamin D) that have been shown to be of great benefit to bone health (17). Moreover, PTH and 25(OH)D are

very involved in the regulation of circulating ionized calcium and may also help modulate changes body composition by affecting adipose and muscle tissue metabolism (40).

At one time during the protocol (week 7), as was also the case in Hartman et al. (15), subjects had blood samples drawn to measure the acute responses of glucose, insulin, amino acids, and hormones (free testosterone, growth hormone (GH), and insulin-like growth factor (IGF-1)) to one daily bout of leg resistance exercise and drink consumption. In brief, subjects reported to the laboratory and had a catheter inserted in an antecubital vein, which was kept patent with an occasional saline flush. A single blood sample was taken before exercise and processed for serum, plasma, and amino acids as described previously (15,38). Subjects then performed a standard leg resistance exercise workout and consumed their drinks as part of their normal training routine and then had their blood drawn immediately after exercise, at 15, 30, 60, and 90 min.

Statistics. Results in the text are expressed as mean \pm SE, and differences were considered significant at $P < 0.05$. Data were analyzed using SIGMASTAT statistical software (version 3.10, © 2004; Systat Software Inc., San Jose, CA). Two-way, repeated-measures ANOVA with time (before and after or times postexercise with the blood sampling) as the within-subjects factor and group (milk and control) as the between-subjects factor were carried out for all body composition variables, dietary variables, strength changes, prestudy and poststudy blood measures, and acute blood measures. Significant interactions uncovered by ANOVA were further examined *post hoc* by Tukey's honestly significant difference, with adjustments for multiple comparisons. Mean changes from baseline (insets in graphs) were calculated and statistically analyzed using unpaired Student's *t*-tests.

RESULTS

Participants. Twenty, young, healthy women participated in this study. Subjects were of similar weight, height, and age (MILK: BMI = $26.2 \pm 4.2 \text{ kg}\cdot\text{m}^{-2}$, age = $23.2 \pm 2.8 \text{ yr}$; CON: BMI = $25.2 \pm 3.8 \text{ kg}\cdot\text{m}^{-2}$, age = $22.4 \pm 2.4 \text{ yr}$). Subject compliance with the daily drinks and exercise training was excellent with all subjects in both MILK and CON, consuming almost all their assigned drinks in the appropriate manner and completing $92\% \pm 2\%$ of their scheduled exercise sessions. Moreover, both the drinks and the exercise protocol were well tolerated, with no major adverse side effects of increased dairy consumption or adverse events relating to exercise. Some subjects reported mild cases of upper-body ($n = 3$ in MILK and $n = 2$ in CON) and lower-body ($n = 1$ in MILK) tendonitis. In these situations, those affected were instructed to rest the area for 1–2 wk by refraining from doing the exercises that aggravated their condition until symptoms resolved. Importantly, no subject developed a chronic injury that did not resolve with rest and that could not be managed by application of

TABLE 1. Estimated dietary intakes by group before (Pre) and after (Post; 12 wk) exercise training.

Variable	Milk		Control		ANOVA Group × Time Interaction
	Pre	Post	Pre	Post	
Energy (kcal·d ⁻¹)	2125 ± 94	2280 ± 85*	2027 ± 75	2227 ± 97*	<i>P</i> = 0.589
Protein (g·d ⁻¹)	70 ± 7	90 ± 8*,†	71 ± 6	70 ± 4	<i>P</i> = 0.030
Carbohydrate (g·d ⁻¹)	300 ± 11	309 ± 10	282 ± 9	322 ± 13*	<i>P</i> = 0.045
Fat (g·d ⁻¹)	72 ± 4	76 ± 3	68 ± 3	74 ± 5	<i>P</i> = 0.787
Calcium (mg·d ⁻¹)	792 ± 42	1561 ± 88*,†	915 ± 94	1030 ± 118*	<i>P</i> < 0.001

* Significantly different from Pre and Post within a group, *P* < 0.05.

† Significantly different from control at the same time point, *P* < 0.05.

ice and/or short-term use of nonprescription analgesics. Individual results from subjects who sustained mild injuries were neither below the mean value nor out of the 95% confidence interval for the whole group with respect to strength and lean mass gains so their data are included in the analyses.

Dietary data. Table 1 illustrates the dietary intake data from MILK and CON as estimated from the subject's 3-d diet records preintervention and postintervention. There was a significant time effect for energy intake with total energy being significantly higher in both MILK and CON postintervention compared with preintervention (*P* < 0.01). A time × treatment interaction existed for protein such that protein intake only increased in MILK preintervention to postintervention (*P* < 0.01), and MILK was significantly greater than CON postintervention (*P* < 0.05). Carbohydrate intake increased significantly preintervention to postintervention in CON but not in MILK (time × treatment interaction, *P* < 0.05). Dietary calcium intake increased

significantly in both groups over time albeit to a greater extent in MILK than CON (both *P* < 0.05), and calcium intake was significantly greater in MILK versus CON postintervention (*P* < 0.01). There were no time, group, or interaction effects for dietary fat intake.

Body composition. Total body mass remained constant over the 12 wk in MILK (72.0 ± 4.1 to 72.5 ± 3.8 kg, *P* = 0.29) but increased slightly in CON (68.3 ± 4.1 to 69.1 ± 4.0 kg, *P* < 0.05). There was a group × time interaction such that fat mass declined only in MILK (−1.6 ± 0.4 kg vs −0.3 ± 0.4 kg, *P* < 0.02; Fig. 1). Lean mass increased with training in both groups (*P* < 0.01; Fig. 2), with a greater net increase after 12 wk in MILK versus CON (1.9 ± 0.2 vs 1.1 ± 0.2 kg, respectively, *P* < 0.01; inset in Fig. 2).

Serum 25-hydroxyvitamin D (25[OH]D), parathyroid hormone (PTH), and markers of bone turnover. During the 12 wk, 25[OH]D increased significantly in both MILK (58.4 ± 3.5 to 64.8 ± 3.5 nM) and CON (53.7 ± 4.9 to 56.5 ± 4.0 nM, *P* < 0.05; Fig. 3), with the change from

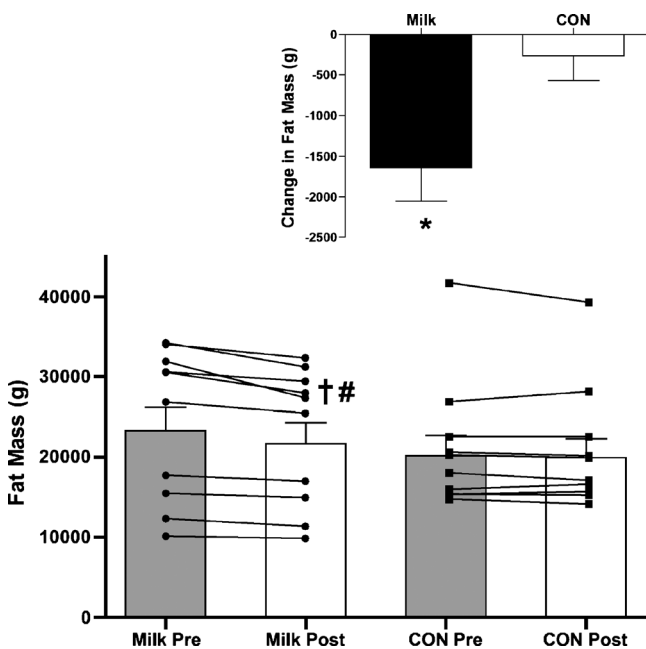


FIGURE 1—Total body fat mass before and 12 wk after resistance training in MILK (*n* = 10) and CON (*n* = 10). Individual subject's pre- and postresponses are represented by the lines spanning the length between the bars. The inset graph shows the change in fat mass from baseline. Time × group interaction: *P* < 0.02. †Significantly different from Pre within the same group (MILK: *P* < 0.01). #Significantly different from CON at the same time point (*P* < 0.05). *Significantly different from CON in the change from baseline in inset (*P* < 0.02). Values are presented as mean ± SE.

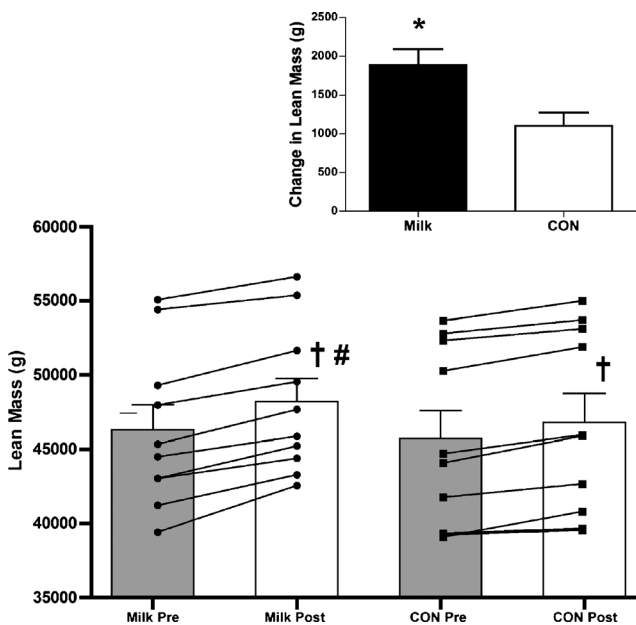


FIGURE 2—Total body lean mass before and 12 wk after resistance training in MILK (*n* = 10) and CON (*n* = 10). Individual subject's pre- and postresponses are represented by the lines spanning the length between the bars. The inset graph shows the change in lean mass from baseline. Time × group interaction: *P* < 0.01. †Significantly different from Pre within the same group (*P* < 0.01 for both). #Significantly different from CON at the same time point (*P* < 0.05). *Significantly different from CON in the change from baseline in inset (*P* < 0.01). Values are presented as mean ± SE.

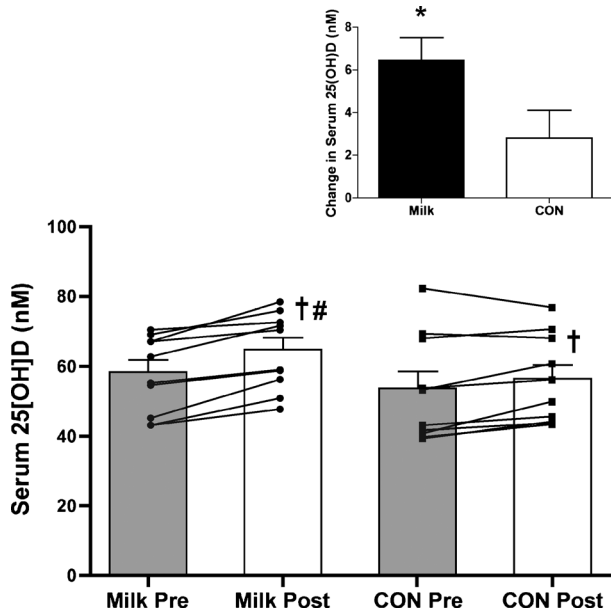


FIGURE 3—Serum 25-hydroxyvitamin D (25[OH]D) before and 12 wk after resistance training in MILK ($n = 10$) and CON ($n = 10$). Individual subject's pre- and postresponses are represented by the lines spanning the length between the bars. The inset graph shows the change in 25[OH]D from baseline. Time \times group interaction: $P < 0.05$. †Significantly different from Pre within the same group (MILK: $P < 0.01$; CON: $P < 0.05$). #Significantly different from CON at the same time point ($P < 0.05$). *Significantly different from CON in the change from baseline in inset ($P < 0.05$). Values are presented as mean \pm SE.

baseline being significantly greater for MILK ($+6.5 \pm 1.1$ vs $+2.8 \pm 1.3$ nM (CON), $P < 0.05$; inset in Fig. 3). Prestudy 25[OH]D levels in MILK and CON ranged from 43.5 to 71.2 nM and from 39.8 to 83.1 nM, respectively, and post-study levels ranged from 48.2 to 79.2 nM and from 43.8 to 77.6 nM, respectively. All subjects except for one in CON had preintervention and postintervention 25[OH]D concentrations of less than 80 nM and were therefore considered insufficient with respect to circulating vitamin D levels (11).

PTH decreased significantly only in MILK from 6.1 ± 0.3 to 4.9 ± 0.4 pM ($P < 0.01$), whereas PTH in CON remained the same (5.7 ± 0.4 to 5.7 ± 0.3 pM, $P = 0.90$; Fig. 4).

Serum osteocalcin increased by 0.63 ± 0.2 ng·mL⁻¹ in MILK and by 0.10 ± 0.24 ng·mL⁻¹ in CON (main effect of time, $P < 0.05$; data not shown). No significant change was observed in serum BSAP (MILK = $+0.51 \pm 0.5$ U·L⁻¹; CON = -0.11 ± 0.39 U·L⁻¹). Serum CTX decreased from 0.54 ± 0.05 to 0.47 ± 0.04 ng·mL⁻¹ in MILK and from 0.55 ± 0.05 to 0.51 ± 0.04 ng·mL⁻¹ in CON (main effect of time, $P < 0.005$; data not shown).

Acute blood metabolite and hormone responses. Subjects underwent one acute testing session during the seventh week (i.e., midpoint) of the protocol. Blood glucose, plasma insulin, amino acids, and several anabolic hormones were measured before and at various time points after a usual bout of leg resistance exercise and study drink consumption. Both blood glucose and plasma insulin were increased at all time points postexercise and drink con-

sumption in CON with no change in MILK ($P < 0.01$; see Supplemental digital content 1 (<http://links.lww.com/MSS/A19>), which shows the acute blood glucose and plasma insulin responses). As expected, only after milk consumption was there a significant corresponding rise in plasma essential amino acids, branched chain amino acids, and leucine ($P < 0.01$; see Supplemental digital content 2 (<http://links.lww.com/MSS/A20>), which shows the acute venous blood amino acid concentrations). Moreover, at 60 min postexercise, when an additional 500 mL of milk was consumed, the plasma amino acid levels rose again accordingly. Testosterone and free testosterone remained unchanged after the exercise bout (Fig. 5). In contrast, GH and IGF-1 both increased after exercise and drink consumption in both groups (main effect of time, $P < 0.05$), with no significant differences between MILK and CON (Fig. 5).

Strength. Preexercise and postexercise training changes in voluntary 1RM strength are shown in Table 2. Both MILK and CON experienced strength gains in all of the exercises performed. There was a time \times treatment interaction for the bench press and a trend toward significance for chest flies such that MILK showed greater increases in strength posttraining versus CON ($P < 0.05$ and $P = 0.086$, respectively).

DISCUSSION

We report here that the consumption of fat-free fluid milk versus an isoenergetic carbohydrate drink immediately after

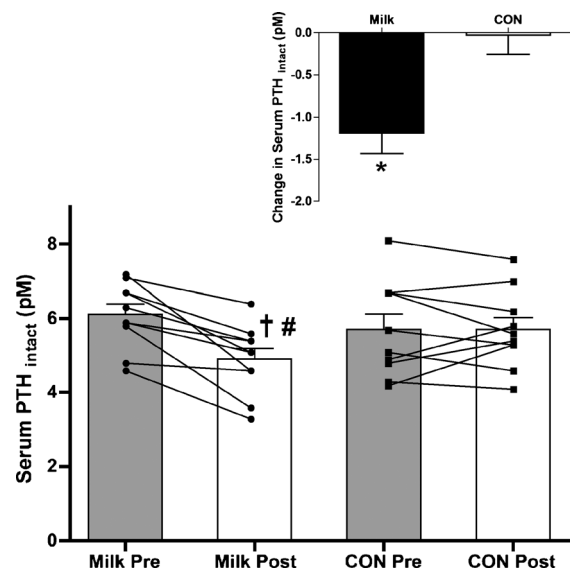


FIGURE 4—Serum parathyroid hormone (PTH) before and 12 wk after resistance training in MILK ($n = 10$) and CON ($n = 10$). Individual subject's pre- and postresponses are represented by the lines spanning the length between the bars. The inset graph shows the change in PTH from baseline. Time \times group interaction: $P < 0.01$. †Significantly different from Pre within the same group (MILK: $P < 0.01$). #Significantly different from CON at the same time point ($P < 0.05$). *Significantly different from CON in the change from baseline in inset ($P < 0.005$). Values are presented as mean \pm SE.

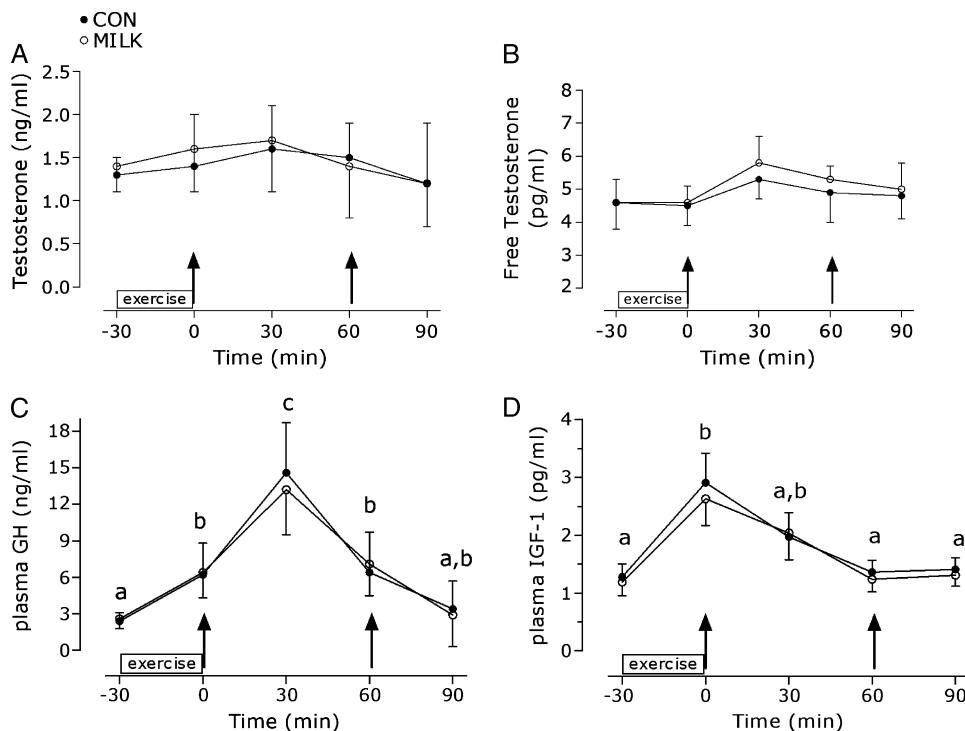


FIGURE 5—Acute hormone response (testosterone (A), free testosterone (B), plasma growth hormone (GH) (C), and plasma insulin-like growth factor (IGF-1) (D)) after exercise and drink consumption in MILK (open circles; $n = 10$) versus CON (closed circles; $n = 10$). Blood samples were taken before, right after, and for an additional 90 min after exercise. The arrows indicate the time of drink consumption (carbohydrate or milk). Main effect of time for GH (C) and IGF-1 (D), $P < 0.05$; mean values at certain time points with different letters are significantly different from baseline, $P < 0.05$. Values are presented as mean \pm SE.

and 1 h after resistance exercise resulted in significantly greater fat mass loss and lean mass and strength gains in young, healthy women performing resistance training 5 d·wk⁻¹ for 12 wk. Body mass did not change in the milk group (MILK) but increased in the control group (CON). We observed significantly greater changes in 1RM strength with some upper-body exercises in women consuming milk.

We chose to study the postexercise consumption of fat-free milk versus simple carbohydrate in young women for several reasons. These related not only to the established evidence supporting greater muscle mass gains with milk proteins postexercise but also with the general goal of promoting the consumption of healthy, low-fat dairy foods that are recommended for this population (13,27). Mechanistically, milk proteins promote anabolism by inducing a greater muscle protein synthetic response, and this effect is greater

than that observed with other proteins (8,28,34,35,38). Concurrent with the gains in lean mass, the women consuming milk showed a markedly greater fat mass loss versus the controls; we had made a similar observation in our previous work in men (15). The reasons for this differential fat mass loss are unclear; however, putative mechanisms involving the interplay between PTH, vitamin D metabolite 1,25-dihydroxyvitamin D (1,25-[OH]₂D), and serum calcium may be relevant. For example, we observed a reduction in PTH in the milk group that may have decreased 1,25-[OH]₂D, thereby increasing lipolysis at the cellular level. Several comprehensive reviews have been written on this topic (33,40). Therefore, with the aforementioned mechanism in mind and noting the observed gains in lean mass, it is entirely possible for the milk group to favorably change their body composition without overt weight loss.

TABLE 2. Single repetition maximum (1RM) strength by group before and after exercise training.

Variables	Milk ($n = 10$)			Control ($n = 10$)			ANOVA Group \times Time Interaction
	Before (lb)	After (lb)	Change (%)	Before (lb)	After (lb)	Change (%)	
Shoulder press	70 \pm 4	121 \pm 2	73	67 \pm 4	108 \pm 6	61	$P = 0.116$
Bench press	81 \pm 6	139 \pm 4	71	80 \pm 6	118 \pm 6	47	$P = 0.029$
Triceps push down	51 \pm 4	89 \pm 3	75	48 \pm 5	77 \pm 3	60	$P = 0.127$
Chest flys	84 \pm 7	153 \pm 7	82	80 \pm 4	133 \pm 8	66	$P = 0.086$
Lat pull down	74 \pm 4	112 \pm 3	52	75 \pm 4	109 \pm 4	45	$P = 0.487$
Bicep curl	47 \pm 3	78 \pm 4	65	46 \pm 6	79 \pm 6	72	$P = 0.702$
Leg press	335 \pm 27	680 \pm 31	103	346 \pm 22	627 \pm 18	81	$P = 0.108$
Hamstring curl	103 \pm 10	159 \pm 17	54	93 \pm 7	149 \pm 7	60	$P = 0.945$
Knee extension	151 \pm 14	246 \pm 17	63	149 \pm 7	233 \pm 14	56	$P = 0.481$

Main effect of time (after > before) for all exercises, except the values italicized, which indicate a group \times time interaction.

A major difference between our study and previous observations of greater fat mass loss with dairy consumption (33,40) is that our trial was not a weight loss trial but rather one in which gains in weight (i.e., as muscle mass) might have been expected. Thus, because the milk group did not gain any weight, we have reported here a significant and highly favorable body compositional change. The increased dairy consumption (fat-free milk) versus supplemental carbohydrate resulted in simultaneous lean mass gains and fat mass losses in young women engaging in high-volume resistance exercise. One recent study also assessed the effect of dairy consumption and resistance exercise in young women. The women consumed three servings per day of low-fat yogurt, a product with equal protein and no calcium or vitamin D, or a carbohydrate control of equal calories devoid of protein, calcium, and vitamin D (37). After 8 wk of resistance training, subjects gained lean mass and lost fat mass, but there were no significant differences between groups. Reasons for this may simply relate to the fact that providing only 5 g of protein (the amount in one yogurt) after resistance exercise (37) would have been far lower than the optimal postexercise protein dose (~20 g) to maximally simulate protein synthesis above that already achieved with resistance exercise alone (24).

Several other studies have assessed the effect of different resistance training programs in women in the absence of a systematic dietary intervention. One of the largest resistance exercise studies carried out by Hubal et al. (21) demonstrated that men had slightly greater increases in muscle cross-sectional area than women, but women had significantly greater relative incremental changes in isometric and dynamic strength compared with men. The same authors also reported a wide range of variability with respect to strength and muscle mass gains after resistance training in men and women, leading the authors to conclude that the relative response to hypertrophic stimuli is not sex dependent and cannot be strongly dictated by the hormonal environment (21). In our study, we observed no change with our acute exercise protocol in both total and free testosterone after heavy leg resistance exercise. At the same time, we observed changes in GH and IGF-1 that were identical between the groups. Thus, these effects do little to explain the differential lean mass gains we observed in those women consuming milk. It has been shown that women can undergo significant hypertrophy and hallmark resistance training-induced muscle fiber type shifts in as little as 6 wk with heavy resistance training (similar to men) (31), an effect that is unlikely to be related to changes in sex hormones like testosterone.

Insofar as muscular strength is concerned, although gains were evident in both groups for all exercises performed, the women consuming milk showed significantly greater 1RM increases in certain upper-body exercises versus the control group. There are several reasons why we propose this may have occurred. It is generally thought that untrained women have half the upper-body strength and about two to three

the lower-body strength than their untrained male counterparts (23). Hence, a potential reason for the greater strength gains in women (and lack thereof in men [15]) with milk consumption may reflect a greater potential for change in women because of their lower initial upper-body strength. A similar effect was also observed by Hubal et al. (21). Although we did not directly measure changes in muscle cross-sectional area and fiber size, lean muscle mass gains (assessed by DXA) and, in some instances, strength gains have been shown to be good surrogates for muscle hypertrophy in other longer-term training studies (5). Thus, it is entirely possible given the differences in whole-body lean mass we observed that our female subjects also showed a direct and likely differential (i.e., MILK > CON) fiber-hypertrophic response.

As an important outcome in this study, we measured circulating serum vitamin D as 25-hydroxyvitamin D (25[OH]D), parathyroid hormone (PTH), and markers of bone turnover (osteocalcin and BSAP as markers of bone formation and CTX as a marker of bone resorption) pre-intervention and postintervention. We were interested in uncovering the effect of longer-term milk consumption on these variables in women with respect to bone health and vitamin D status. It is generally accepted that “sufficient” levels (albeit probably not optimal (36)) of circulating vitamin D, defined as a 25[OH]D level ≥ 80 nM, are necessary for optimal bone health (11,17). At a sufficient or higher 25[OH]D level, intestinal calcium absorption plateaus, and both skeletal calcium resorption and PTH levels have been shown to stabilize (11). This has been seen as an indicator of reduced bone remodeling (11). We hypothesized that subjects in the milk group consuming 1 L·d⁻¹ of milk for 12 wk (providing 1200 mg·d⁻¹ of calcium and 360 IU·d⁻¹ of vitamin D) would show increases in serum 25[OH]D and a possible reduction in PTH levels after the intervention. The current adequate intake for vitamin D is only 5 μ g·d⁻¹ (200 IU·d⁻¹) for women age 19–50 yr (22). However, an emerging consensus is that this level of intake is perhaps too low and does little to facilitate intestinal calcium absorption (and prevent bone resorption) to sustain adequate calcium homeostasis (19). In our study, the milk intake alone provided subjects with 180% of the adequate intake per day. Because an intake of 40 IU·d⁻¹ of vitamin D3 has been shown to raise serum 25[OH]D by 0.7–1 nM in healthy young men (16,36), we would expect our subjects’ levels to rise by approximately 6.3–9 nM. As expected, we observed a significant increase in 25[OH]D of 6.5 nM in the milk group (and also 2.8 nM in the control group). However, the actual levels of circulating 25[OH]D postintervention only ranged from 48.2 to 79.2 nM in those consuming milk, and thus these subjects were still either vitamin D insufficient (50–80 nM (11)) or deficient (<50 nM [11]).

Despite the subjects’ insufficient vitamin D status, we observed significant reductions in serum PTH in the milk group. This was accompanied by significant changes in markers of bone turnover, specifically a reduction in serum

CTX and an increase in serum osteocalcin. PTH stimulates bone resorption (18), and the increased dietary calcium intakes, as seen in the milk group, resulted in a reduction in PTH. Although we know that adequate vitamin D levels are also necessary for proper intestinal absorption of dietary calcium (14,17), it may be possible that, as seen in this study, a calcium intake of at least 1200 mg (actual dietary intake of subjects in MILK = 1560 mg·d⁻¹), which is above the current DRI of 1000 mg (22), adequately maintained serum calcium within its appropriate circulating range. Thus, the observed reduction in PTH in the subjects consuming 1 L of milk per day indicates appropriate feedback control and may signify a possible reduction in bone resorption. To further elucidate this point, we fully acknowledge that it would have been more comprehensive to include in our measurements serum calcitonin and 1,25-[OH]₂D because these two hormones are also intimately involved in the regulation process; this is a consideration for future studies.

In conclusion, the consumption of 500 mL of fat-free fluid milk immediately after and 1 h after resistance exercise 5 d·wk⁻¹ for 12 wk promoted greater gains in skeletal muscle mass, greater losses of fat mass, and increased strength in some exercises in young women compared with those who consumed an isoenergetic carbohydrate drink. Furthermore,

we observed an increase in serum 25[OH]D levels in MILK that was of a reasonable magnitude. However, despite the vitamin D intake being 180% above the current DRI, all of our subjects still remained below sufficiency postintervention. We also observed reductions in serum PTH related to increased dietary calcium intakes, and this along with the observed increase in osteocalcin and decrease in serum CTX may positively affect bone turnover in the women consuming milk. In summary, the consumption of milk in young women undergoing resistance training resulted in healthful changes in body composition, strength, and also potentially in bone.

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