Effects of Energy Restriction and Exercise on Bone Mineral Density during Lactation

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Abstract:

Modest energy restriction combined with resistance training (RT) has been shown in nonlactating women to protect bone during periods of weight loss. However, there is a paucity of research on dietary interventions and exercise in lactating women aimed at promoting bone health and weight loss.

Purpose: This study aimed to investigate the effects of energy restriction and exercise on bone mineral density (BMD) and hormones during lactation.

Methods: At 4 wk postpartum, participants were randomized to either a 16-wk intervention (diet restricted by 500 kcal and RT 3 d·wk-1) group (IG = 14) or minimal care group (CG = 13). Measurements included BMD by DXA, three 24-h dietary recalls, and hormones. Repeated-measures ANOVA was used to test for group differences over time.

Results: Energy intake decreased more in IG (613 ± 521 kcal) than CG (171 ± 435 kcal) (P = 0.03). IG lost more weight (5.8 ± 3.5 kg vs CG = 1.6 ± 5.4 kg, P = 0.02). BMD decreased over time, $P < 0.01$, with no group differences in lumbar spine (IG = 3.4% ± 2.5%, CG = 3.7% ± 3.3%) or hip (IG and CG = 3.1 ± 1.8%). Prolactin and estradiol decreased over time in both groups, $P < 0.01$. Basal growth hormone remained stable; however, there was a significant increase in growth hormone response to exercise in IG.

Conclusions: These results suggest that moderate energy restriction combined with RT promotes weight loss with no adverse effects on BMD during lactation.

Keywords: Diet | Breast-feeding | Postpartum weight loss | Physical activity

Article:

Obesity in America has risen to epidemic proportions during the last 20 yr. Using data from the 2007–2008 National Health and Nutrition Examination Survey, Flegal et al. (9) estimated that 25.5% of American women between the ages of 20 and 39 yr were overweight and 34% were obese. Childbearing may be one of the causes for the high prevalence of overweight and obesity among women because excessive weight gain during pregnancy has been shown to be a positive predictor in long-term postpartum weight retention (21). Rooney and Schauberger (28) reported that excess gestational weight gain, failure to lose weight during the early postpartum period, lack of aerobic exercise, and breast-feeding for less than 3 months were positive predictors of weight gain one decade later.

Few randomized trials have investigated energy restriction during lactation to promote postpartum weight loss. McCrory et al. (22) reported that a short-term (11-d) energy deficit (1000 $kcal \cdot d^{-1}$) during lactation resulted in an average weight loss of 1.9 kg and had no effect on breast milk composition and volume. Lovelady et al. (20) found that a moderate calorie restriction (500 $kcal \cdot d^{-1}$) coupled with increased aerobic exercise resulted in significant weight loss (4.8 ± 1.7 kg) and no adverse effects on infant growth (weight or length) from 4 to 14 wk postpartum.

Although energy restriction is necessary for weight loss, some researchers report loss of bone mineral density (BMD) with reduced energy intake (30). In studies that have investigated extremely low levels of energy intakes (405 to 1000 $kcal \cdot d^{-1}$ or <55% of recommended intake) (7) or in studies with rapid weight loss (>14%) during short periods of time (<3–4 months) (38), significant reductions in bone density have been reported in both men and women. However, modest restriction in energy intake has been shown in premenopausal women to improve body composition and not affect bone during periods of weight loss (27).

This possible decrease in BMD is of concern when recommending energy restriction after birth because women lose BMD during lactation (15, 23). Maternal bone is lost at a rate of 1%–3% per month, with a greater loss (1%–10%) at the trabecular-rich sites, lumbar spine, and hip (11). The bone loss is driven by an increased demand for calcium in breast milk (approximately 200–400 mg of $calcium \cdot d^{-1}$) (11), combined with elevated serum prolactin concentrations and lower concentrations of estradiol (15). In most women, bone loss is usually reversed after weaning, when prolactin concentration is decreased and estradiol concentration is increased with normal menstruation (15). However, not all studies report complete recovery of bone loss (23).

Exercise combined with a modest restriction in energy intake has been shown in premenopausal and postmenopausal women to improve body composition and protect bone during weight loss (25, 31). We previously investigated the effects of exercise (aerobic and resistance training) on BMD in fully breast-feeding women (19). The exercise group performed 45 min of moderate-intensity walking and 30 min of resistance exercise 3 $d \cdot wk^{-1}$. Compared with the control group, the exercise group had less lactation-induced bone loss in the lumbar spine (-4.8% ± 0.6% vs -7.0% ± 0.3%, $P < 0.01$) (19). Although the study design did not have an energy restriction component, both groups reduced their dietary intake and lost an average of 3.5 kg.

Growth hormone (GH) plays a critical role in bone mass maintenance in adults by regulating bone remodeling (36). This process has been shown to be highly complex, involving interactions of circulating GH, insulin-like growth factors (IGF), the binding proteins for IGF, as well as local production of IGF acting in a paracrine and/or autocrine manner (36). There is emerging evidence that estrogen modulates GH action by suppressing cellular signal transduction and reducing IGF-1 gene expression (16), resulting in a relative resistance to the stimulatory effects of GH on IGF-1 production (36). Given the crucial role of the GH/IGF-1 axis for bone homeostasis, physiological stimulation of GH secretion by mechanisms such as exercise may be particularly important for attenuation of bone loss during pregnancy and lactation. Increases in GH have consistently been observed after acute bouts of both aerobic and resistance exercise in eumenorrheic women (8, 14), but this has not been extensively investigated in lactating women. One study (5) investigated the effects of acute moderate intensity aerobic exercise on GH output during pregnancy (22 and 33 wk of gestation) and lactation (14 wk postpartum) in active women and found that the preexercise-to-postexercise increase in GH was greater during lactation, but estrogen and prolactin concentrations were not reported in this study.

In overweight breast-feeding women, weight loss has been shown to be safe without compromising infant growth (20). In addition, aerobic and resistance exercise slowed the loss of BMD (19) during lactation in normal to overweight women. However, the effect of energy restriction on BMD has not been investigated in lactating women. Therefore, the primary purpose of this study was to determine whether a diet and exercise intervention would promote weight loss without increasing the loss of BMD in fully breast-feeding, overweight women. A secondary aim was to describe changes in hormones related to bone metabolism (i.e., prolactin, estradiol, and GH).

METHODS

Participants were recruited through prenatal classes and flyers posted within the community and obstetricians' offices. An interviewer determined eligibility by telephoning women after the birth of their infant. Eligibility criteria included vaginal delivery, less than 3 wk postpartum with a self-reported body mass index (BMI) between 25 and 30 $kg \cdot m^{-2}$, fully breast-feeding (not supplementing with formula), age 23–37 yr, and participation in physical activity <3 $d \cdot wk^{-1}$ for the past 3 months. Potential participants were excluded if they delivered by cesarean section, had a history of smoking during pregnancy, had preexisting medical conditions that affected hormone levels, or if exercise was contraindicated. Sample size was determined from the results of two previous studies (19, 20). A final sample size of 26 participants (13 per group) was estimated to provide enough power (80%), with a two-sided *[alpha]* level of 0.05, to detect differences of 2% in change in lumbar spine BMD (e.g., the minimal care group loses 7% and the intervention group loses 5%) and change in weight of 2.5 kg. All participants agreed to the randomization, all were medically cleared for exercise by their physicians, and all gave written informed consent before the baseline measurements. After baseline measurements, participants were randomized, stratified by parity, into either an intervention (diet and exercise) group or a minimal care group. A computer-generated random numbers table was used to stratify primiparous and multiparous women into one of two groups. Group assignment was concealed in individual sealed envelopes by a third party not affiliated with the study. The participant was handed the sealed envelope to learn of group assignment on completion of all baseline measurements to prevent bias baseline results by the investigators. Procedures followed were in accordance with the ethical standards of the institution on human experimentation. The University of North Carolina at Greensboro Institutional Review Board approved the study protocol. The study was registered with ClinicalTrials.gov (NCT00966381).

Laboratory Measurements

Measurements at baseline (4 ± 1 wk postpartum) and end point (20 ± 2 wk postpartum) included maternal and infant anthropometrics, body composition, BMD, dietary intake, cardiovascular fitness test, muscular strength, and blood draws for hormone analysis.

Assessment of Body Composition and Bone Mineral Density

Participants were measured without shoes and in light clothing. Height was measured using a standardized stadiometer (235 Heightronic Digital Stadiometer, Snoqualmie, WA). The participant's weight was measured on a digital scale (Tanita BWB-800S, Arlington Heights, IL). A Gulick tape measure was used to measure waist and hip circumference. Waist circumference was defined as the narrowest part of the torso above the umbilicus and below the xiphoid process (1). Hip circumference was defined as a horizontal measure taken at the maximum circumference of the buttocks (1). The infant's weight was measured on a SECA 334 (SECA, Hanover, MD) pediatric digital scale and a pediatric measuring board was used to measure length.

Bone density, mineral concentration, and area were measured with dual-energy x-ray absorptiometry (Lunar Prodigy Adv.; Lunar Radiation Corp., Madison, WI; QDR enCORE software version 11.20.068). A trained dual-energy x-ray absorptiometry technician positioned the subject and performed the scans to ensure precision and accuracy. In addition, standard scan methods were used. Participants were placed in the supine position, still and flat on an x-ray table while the fan-beam scanner made a series of transverse scans from head to toe in 0.6- to 1.0-cm intervals. Three total scans were performed: total body (total bone density, mineral content, and area), lumbar spine (L1–L4), and total left hip (femoral neck, trochanter, and Ward triangle).

Assessment of Dietary Intake

Dietary intake was assessed by 24-h dietary recalls at baseline and end point. Dietary recalls were collected by telephone or in person using the Nutrition Data System for Research (NDSR, University of Minnesota, MN) software, on three separate days in the same week. NDSR manages the collection of dietary data through a series of data entry windows, using a multiple pass system. NDSR has been previously validated against doubly labeled water and proved to be an accurate method to assess energy intake (6, 24).

Assessment of Cardiovascular Fitness

Cardiovascular fitness was determined through a modified Balke protocol using a submaximal treadmill test (1). An HR monitor (Polar, Inc., Woodbury, NY) was used to measure resting HR (RHR) and HR during exercise testing. Blood pressure, using a digital monitor, and RHR were obtained before the exercise testing. Participants warmed up on the treadmill for 5 min and were instructed to self-select a “brisk but slightly uncomfortable” speed at either a walk (< 3.7 mph) or a jog (> 3.7 mph) pace. The speed remained constant throughout the test. The incline of the treadmill increased in increments of 2.5% every 3 min to ensure HR had reached steady state before progressing to the next stage. HR and RPE were recorded at the end of the second minute and before progression to the next stage. The test was terminated once the participant’s HR reached 85% of their predicted HR maximum calculated using the HR reserve formula [(220 - age - RHR) × 85% + RHR] or the participant requested to stop the test. Predicted $V \cdot O_2$ was calculated based on one of the following equations depending on whether the participant walked or jogged for the treadmill test (1):

Predicted maximal oxygen consumption ($V \cdot O_{2max}$) was calculated using a linear regression equation with HR as the independent variable and the dependent variable was predicted $V \cdot O_2$.

Assessment of Muscular Strength and Endurance

Muscular strength was assessed using the 1-repetition maximum (1RM) method (1). Participants were instructed on the proper technique for each exercise before the 1RM test. The 1RM strength exercises were squats, bench press, bent-over row, stiff leg deadlift, and seated military press. Adjustable dumbbell weights were used for the strength assessment. One set of 10 repetitions of trunk rotations, hip, and knee X-chops was used for the warm-up using a 2-kg medicine ball. Before each 1RM test for each exercise, participants performed one set of 10 repetitions. Participants began with weights approximately 50%–70% of their perceived capacity for one lift. The weight was increased with each lift, with a 1- to 2-min rest period in between, until the participant could no longer safely perform the exercise with proper technique or was requested to stop. The final weight lifted with the proper technique was recorded as the participant’s 1RM for that exercise. Muscular endurance was assessed using the American College of Sports Medicine protocol for abdominal curl-ups and pushups (1).

Assessment of Hormones

Participants presented to the laboratory in the morning, after an overnight fast and no exercise for 24 h before blood draw. A trained phlebotomist drew blood at the same time each visit (4 and 20 wk postpartum) to control for diurnal variation. Basal samples were collected before the 1RM testing. In addition, blood was drawn immediately after the 1RM testing to determine the acute response of GH to maximum strength exercise. Samples were stored at -70°C until analyzed. Enzyme-linked immunosorbent assay quantization kits (Alpco Diagnostics, Salem, NH) were used to quantify hormone concentrations of prolactin, estradiol, and GH in the serum.

Study Intervention

Intervention group

The intervention group participated in a 16-wk diet and exercise program from 4 to 20 wk postpartum. A research assistant traveled to the participant's homes one to three times per week during the 16-wk intervention to guide mothers with the exercise program and to ensure dietary compliance. The 16-wk exercise protocol consisted of walking 10,000 steps or 3000 aerobic steps per day at least 5 $d \cdot wk^{-1}$ and strength training three times per week. The participants used a pedometer (Omron Healthcare, Inc., Bannockburn, IL) to monitor the number of steps taken per day. Each participant started with a minimum of 4000 steps per day and was instructed to increase their daily step count by 100 to 200 steps per day during the first 4–6 wk until the goal of 10,000 steps per day was reached. An alternative option of reaching 3000 aerobic steps was offered to participants. Aerobic steps were calculated on the pedometer as walking at least 100 steps per minute for at least 10 min continuously. Previous researchers (34) determined that 3000 aerobic steps are equivalent to walking 30 min at a brisk pace.

Strength exercises were progressive and designed to target the core, which includes the region of the body from the gluteal muscles and hip up to the scapula, to stimulate bone formation at the lumbar spine and hip. The combination exercises were variations of the core exercises (squats, bench press, bent-over row, deadlift, and military press) used in 1RM testing. All of the strength exercises were completed in the home with use of handheld dumbbell weights, a stability ball, and a yoga mat. The addition of 50 vertical jumps per session, three times per week was introduced at week 9 of the strength training program to further stimulate bone formation. All exercise sessions were recorded in a logbook to assess compliance to the protocol.

A registered dietitian worked with the participants using *MyPyramid Menu Planner for Moms* (37) to reduce their energy intake and encourage a healthy eating style. Energy needs were calculated using the total energy expenditure equation from the Dietary Reference Intakes for overweight, nonpregnant, nonlactating women (10). An additional 330 kcal was added for breast-feeding and then 500 kcal was subtracted to facilitate a weight loss of 1 $lb \cdot wk^{-1}$. The minimum energy intake prescribed was 1800 kcal. To allow for individualized dietary counseling, participants were asked to log in at least 3 $d \cdot wk^{-1}$ on *MyPyramid Menu Planner for Moms* and enter their dietary intake. The average weekly dietary counseling session lasted about 30 min based on their compliance to meet the *MyPyramid* recommendations; however, participants were encouraged to ask questions during any of the weekly exercise sessions or anytime via e-mail. The participant's weight and circumference, along with the infant's weight, were measured every 2 wk using appropriate portable digital scales (Tanita BWB-800S and SECA 334 infant scale) and a Gulick tape measure.

Minimal care

The minimal care group received standard public health information on nutrition from the American Heart Association twice during the 16-wk intervention. The first handout mailed at 9 wk postpartum focused on eating more nutrient dense foods and less nutrient poor foods (3). The second handout mailed at 16 wk postpartum focused on healthy diet and lifestyle recommendations (2). The minimal care group was asked not to participate in structured exercise or change their dietary habits for 16 wk. On completion of the end point measurement, the minimal care participants were given all intervention materials, including the exercise equipment, exercise protocol and instruction, as well as the dietary prescription.

All participants in both groups were asked to fully breast-feed their babies throughout the 16-wk intervention. Mothers who began supplementing their infants with >4 oz of formula on a regular basis were disqualified from the study. Biweekly contact with all participants was completed to assess the use of formula, use of birth control, return of menses, change in physical activity, and use of dietary supplements. In addition, adverse dietary events (i.e., infant intolerance from the mother's dietary intake) were also recorded. All participants were provided with a multiple vitamin supplement without minerals.

Statistical Analysis

JMP software (v.6.0.0 SAS Institute Cary, NC) was used to analyze data. Student's *t*-test and *[chi]*^{2} analysis were used to compare differences between groups for baseline characteristics. Repeated-measures ANOVA was used to test for differences over time and between groups for body weight, BMD, dietary intake, fitness measurements, and hormones. Results are reported as mean ± SD, with significance set at $P <= 0.05$.

RESULTS

One hundred fifty-four women were initially screened for eligibility (Fig. 1). One hundred twenty-three women were determined to be ineligible (32 = birth by cesarean section, 26 = self-reported postpartum BMI >=30 $kg \cdot m^{-2}$ or <=24.9 $kg \cdot m^{-2}$, 25 = unable to contact after delivery/infant's health/multiple births/lived outside recruitment area, 16 = too young or old, 15 = too active or did not agree to be randomized, and 9 = formula feeding). Thirty-one women were randomly assigned, after completion of baseline measurements (4.3 ± 0.8 wk postpartum), into either the intervention group (n = 16) or the minimal care group (n = 15). Four women (two in each group) did not complete the study and were not included in the baseline measurements. Three women (intervention = 2, minimal care = 1) stopped breast-feeding and introduced formula (>4 $oz \cdot d^{-1}$ on a regular basis) for personal reasons not due to study protocol (e.g., returned to work full time). The fourth (minimal care) moved out of state and was unable to return to complete end point measurements. The baseline characteristics of the four who discontinued the study were not different from the women who completed the study (n = 27).

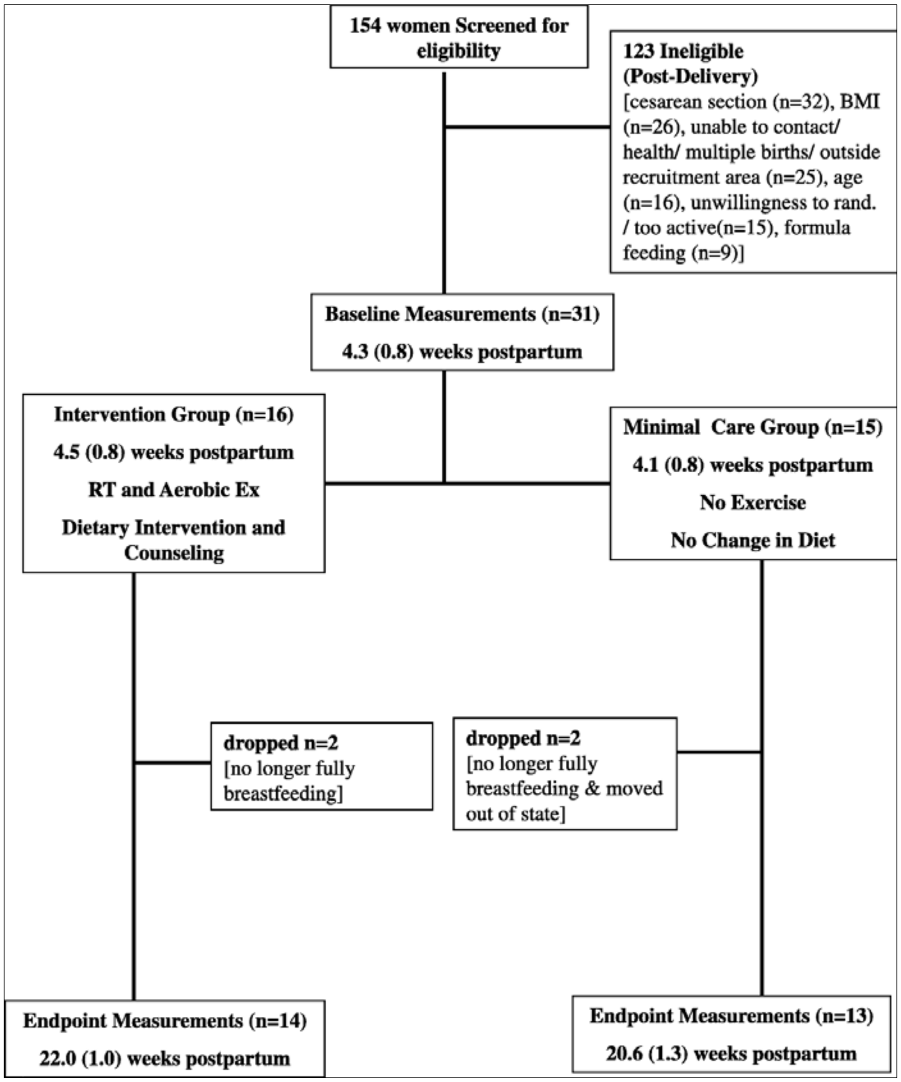

FIGURE 1. Study enrollment flow chart.

No significant differences were seen between eligible participants in the two groups at baseline (Table 1). The screening for BMI (self-reported height and weight) was between 24.9 and 30 $kg \cdot m^{-2}$; however, when height and weight were measured in the laboratory, BMI ranged from 24.5 to 35.2 $kg \cdot m^{-2}$. Four women in the minimal care group had a BMI >30 $kg \cdot m^{-2}$ (range = 30.3–34.6 $kg \cdot m^{-2}$), whereas seven women in the intervention group had a BMI >30 $kg \cdot m^{-2}$ (range = 30.3–35.2 $kg \cdot m^{-2}$).

TABLE 1. Baseline characteristics of the minimal care and intervention groups.[a]

Characteristic	Minimal Care (n = 13)	Intervention (n = 14)
Age (yr)	30.3 ± 3.8	31.9 ± 3.1
Parity (n)		
Primiparous	6	6
Multiparous	7	8
Prepregnancy weight (kg)	68.7 ± 14.9	73.7 ± 10.8

Weight (kg)	74.1 ± 11.5	81.6 ± 10.1
Height (cm)	162.4 ± 6.8	165.8 ± 5.4
BMI (kg·m^{-2})	28.0 ± 3.3	29.7 ± 3.6
Weight of infants (kg)		
Birth	3.3 ± 0.5	3.5 ± 0.4
4 wk	4.2 ± 0.5	4.3 ± 0.3
Sex of infant (n)		
Female	10	10
Male	3	4

[a] All values are means ± SD, unless otherwise indicated. There were no significant differences between groups at baseline.

Twenty-five of the women enrolled were white, non-Hispanic, five black, non-Hispanic (minimal care group = 3, intervention group = 2), and one Hispanic (intervention group). Two white, non-Hispanic and two black, non-Hispanic women (one per group) did not complete the study. All women enrolled had a college education.

The intervention group lost significantly more weight than the minimal care group (-5.8 ± 3.5 vs -1.6 ± 5.4 kg, respectively, $P = 0.03$). Six of the women in the intervention group lost >7.2 kg, which was equivalent to the weight loss goal of the study of 1 lb·wk^{-1}. Five women (36%) in the intervention group and two women in the minimal care group (15%) returned to their prepregnancy weight by end point. Waist and hip circumference significantly decreased in the intervention group (-6.3 ± 3.3 and -5.3 ± 4.1 cm, respectively) compared with the minimal care group (-0.7 ± 9.1 and -1.4 ± 5.6 cm, respectively, $P = 0.03$) for both waist and hip circumference.

Total BMD was similar from baseline to end point; however, total BMC and bone area decreased over time in both groups ($P < 0.01$; Table 2). BMD and BMC in the lumbar spine and hip significantly decreased over time ($P < 0.01$), with no significant differences between groups.

TABLE 2. BMD, content, and area of the minimal care and intervention groups.a

	Minimal Care Group (n = 13)			Intervention Group (n = 14)			
	Baseline	End Point	% Change	Baseline	End Point	% Change	P[b]
Total body							
BMD (g·cm^{-2})	1.186 ± 0.095	1.184 ± 0.110	-0.3 ± 2.4	1.227 ± 0.059	1.213 ± 0.057	-1.1 ± 0.8	NS
BMC (g)	2688 ± 546	2508 ± 358	-5.7 ± 7.0	2839 ± 308	2742 ± 263	-2.9 ± 8.8	0.02
Area (cm^2)	2252 ± 310	2113 ± 146	-5.3 ± 8.3	2317 ± 249	2262 ± 205	-1.8 ± 9.2	0.04
Lumbar spine							

BMD ($g \cdot cm^{-2}$)	1.178 ± 0.164	1.133 ± 0.144	-3.7 ± 3.3	1.254 ± 0.105	1.211 ± 0.100	-3.4 ± 2.5	<0.001
BMC (g)	58 ± 9	54 ± 8	-5.6 ± 5.8	67 ± 10	64 ± 9	-4.9 ± 5.6	0.003
Area (cm^2)	49 ± 4	48 ± 4	-2.0 ± 4.8	54 ± 5	53 ± 5	-1.5 ± 6.0	NS
Hip							
BMD ($g \cdot cm^{-2}$)	1.073 ± 0.146	1.040 ± 0.145	-3.1 ± 1.8	1.056 ± 0.133	1.024 ± 0.134	-3.1 ± 1.7	<0.001
BMC (g)	32 ± 4	31 ± 4	-3.1 ± 2.2	33 ± 4	32 ± 4	-3.2 ± 1.8	<0.001
Area (cm^2)	30 ± 2	30 ± 2	0.1 ± 1.0	31 ± 2	31 ± 2	-0.1 ± 0.6	NS

[a] All values are means ± SD.
[b] Significantly different over time, repeated-measures ANOVA.
BMC, bone mineral content; NS, not significant.

The intervention group reduced their energy intake (-613 ± 521 kcal) compared with the minimal care group (-171 ± 435 kcal, *P* = 0.03; Table 3). The percent of energy from CHO increased, whereas the percent of energy from fat decreased significantly more in the intervention group compared with that in the control group. The intervention group reported consuming a higher amount of dietary calcium at baseline compared with the minimal care group. However, during the study, five women in the intervention group reporting restricting their dairy intake because of “infant intolerance.” Despite the dairy restriction, the intervention group consumed approximately the same amount of calcium from their diet as the minimal care group did at the end measurement. The decrease in dairy products resulted in a decrease in vitamin D intake in the intervention group as well; however, it was not significant (*P* = 0.2). Two women (one in each group) reported taking calcium supplements during the study.

TABLE 3. Reported dietary intake of the minimal care and intervention groups.[a]

	Minimal Care Group (n = 13)		Intervention Group (n = 14)		
	Baseline	End Point	Baseline	End Point	P[b]
Energy					
Kilocalories	2072 ± 544	1901 ± 601	2383 ± 510	1770 ± 433	0.03
Kilocalories per kilogram	28.3 ± 8.1	26.0 ± 4.9	29.8 ± 8.2	23.7 ± 6.8	NS
Percent of energy from					
CHO	50.9 ± 5.5	50.3 ± 6.0	50.5 ± 4.9	54.5 ± 5.2	0.04
Protein	16.0 ± 3.1	17.1 ± 3.3	16.4 ± 3.2	18.3 ± 3.0	NS

Fat	34.4 ± 5.3	33.8 ± 6.2	34.6 ± 4.5	29.1 ± 5.4	0.04
Protein					
Grams	81.9 ± 23.5	80.3 ± 24.2	95.2 ± 16.3	79.8 ± 19.7	NS
Grams per kilogram	1.1 ± 0.4	1.1 ± 0.2	1.2 ± 0.3	1.1 ± 0.3	NS
Calcium (mg)	1023 ± 370	963 ± 254	1344 ± 335	1007 ± 255	0.04
Vitamin D (µg)	4.1 ± 2.6	4.2 ± 2.7	5.0 ± 2.1	3.7 ± 1.9	NS

[a] All values are means ± SD.
[b] Significantly different, time × group, repeated-measures ANOVA.
NS, not significant.

Predicted $\dot{V}O_{2max}$ improved by approximately 9% in both groups during the study (Table 4). The intervention group wore their pedometers on average 97.2 ± 17.5 d (range = 61–112 d) of a possible 112 d. The average daily steps were 4838 ± 2814 with an average of 917 ± 561 aerobic steps. Participants reported that bad weather, lack of time, and no childcare were reasons for the low number of steps recorded during the weekly recording of the pedometer log.

The intervention group had a 91.2% ± 9.9% (range = 66.7%–100%) compliance to the resistance training program (Table 4). The intervention group significantly improved their strength for squats, bent-over row, deadlifts, military press, and push-ups compared with the minimal care group.

TABLE 4. Cardiovascular fitness and muscular strength of the minimal care and Intervention groups.[a]

	Minimal Care Group (n = 13)			Intervention Group (n = 14)			
	Baseline	End Point	% Change	Baseline	End Point	% Change	P[b]
$\dot{V}O_2$(mL·kg^{-1}·min^{-1})	31.2 ± 4.2	33.8 ± 7.2	9.3 ± 16.5	31.8 ± 5.3	34.5 ± 7.2	9.0 ± 14.4	NS
$\dot{V}O_2$(L·min^{-1})	2.3 ± 0.4	2.4 ± 0.6	4.4 ± 19.1	2.6 ± 0.5	2.6 ± 0.7	0.6 ± 14.0	NS
Squats (lb)	88 ± 15	100 ± 15	17 ± 21	89 ± 18	124 ± 19	47 ± 30	<0.001
Bench press (lb)	54 ± 14	59 ± 12	9 ± 16	52 ± 11	62 ± 17	21 ± 26	NS
Bent-over row (lb)	49 ± 11	55 ± 14	10 ± 23	53 ± 16	72 ± 14	48 ± 53	0.005
Deadlift (lb)	83 ± 20	91 ± 24	13 ± 32	90 ± 14	117 ± 18	31 ± 21	0.02
Military press (lb)	41 ± 10	43 ± 10	2 ± 23	40 ± 12	49 ± 9	28 ± 28	0.02

ACSM curl-ups (n)	22 ± 7	25 ± 0	14 ± 33	22 ± 8	25 ± 0	13 ± 43	NS
ACSM push-ups (n)	9 ± 5	15 ± 7	65 ± 51	8 ± 8	20 ± 9	209 ± 189	0.03[c]

[a] All values are means ± SD.
[b] Significantly different, time × group, repeated-measures ANOVA.
[c] Both groups' push-ups also significantly increased over time (P = 0.006), repeated-measures ANOVA.
$\dot{V}O_2$, predicted maximal oxygen consumption; NS, not significant.

Prolactin and estradiol concentrations significantly decreased in both groups during the intervention (Table 5). Three women resumed their menses (one in the intervention group at 11 wk postpartum and two in the minimal care group at 7 and 8 wk postpartum) during the study. The phase of the menstrual cycle was not controlled for at the end point measurement for those three women. Five women in each group started birth control during the study (three per group used the "minipill" and two per group used an intrauterine device). The intervention group started using birth control at 8.9 ± 2.5 wk postpartum, whereas the minimal care group waited until 13.9 ± 6.2 wk postpartum to start birth control. No change in basal GH was observed from baseline to end point. However, there was a greater increase in GH concentration immediately after exercise in the intervention group at the end of the study compared with a decrease in the minimal care group. There were five women who had missed blood draws immediately after 1RM because of collapsed veins: three women in the minimal care group and two women in the intervention group. These participants values are included in the analysis for the basal concentrations (IG = 14, CG = 12) but not the acute response to exercise. The acute response values are the *change* from preexercise to postexercise only in the matched pairs (IG = 12, CG = 9).

There were no differences in infant growth (weight or length) between the two groups. The infants gained an average of 2.7 ± 0.5 kg from baseline to end point in the intervention group, which was similar to the average infant weight gain in the minimal care group of 2.6 ± 0.6 kg. Infants' length was similar between the groups at baseline and end point (intervention = 53.5 ± 1.6 and 64.4 ± 2.4 cm; minimal care = 52.8 ± 1.7 cm and 62.8 ± 2.2 cm, respectively].

TABLE 5. Hormone concentrations of the minimal care and intervention groups.a

	Minimal Care Group (n = 12)b		Intervention Group (n = 14)		
	Baseline	End Point	Baseline	End Point	P
Prolactin ($\mu g \cdot L^{-1}$)	172 ± 119	80 ± 50	164 ± 95	64 ± 22	0.005[c]
Estradiol ($pmol \cdot L^{-1}$)	228 ± 104	91 ± 46	174 ± 86	97 ± 69	<0.01[d]
GH ($\mu g \cdot L^{-1}$)					
Basal state	6.5 ± 6.1	6.6 ± 6.7	6.1 ± 3.9	7.5 ± 7.7	NS
Acute exercise	6.8 ± 6.5	3.6 ± 5.1	1.3 ± 4.0	8.4 ± 8.9	0.003[f]

response (change from basal to after exercise)[e]					

[a] All values are means ± SD.
[b] Blood samples were not collected in one participant in the minimal care group.
[c] Significantly different over time, repeated-measures ANOVA.
[d] Significantly different over time, and time × group, repeated-measures ANOVA.
[e] Blood samples were not collected after exercise in three control and two intervention participants.
[f] Significantly different, time × group, repeated-measures ANOVA.
Basal state, fasted before exercise.

DISCUSSION

Women in the intervention group reduced their energy intake and lost significantly more weight but did not lose more BMD and BMC than the minimal care group. These weight loss results are similar to those in our previous study of overweight lactating women. That intervention began at the fourth week postpartum and was 10 wk in length with a moderate calorie reduction (500 kcal·d^{-1}) combined with aerobic exercise (walking) (20). The diet and exercise group lost 4.8 kg of body weight, and similar to the results in this current study, infant growth was not affected.

However, in this current study, despite reporting a 613-kcal deficit, the intervention group failed to achieve an average weight loss of 1 lb·wk^{-1} and only 6 of the 14 lost >7.2 kg during the 16 wk. Some women may have underreported their dietary intake and did not decrease their energy intake by 500 kcal·d^{-1}. Underreporting is more likely to occur in overweight women compared with women of normal weight (18). In addition, the women were unable to achieve the aerobic exercise prescription of walking 10,000 steps per day, which would have facilitated further weight loss. The participants in our previous study (20) were compliant to the 45-min aerobic sessions 4 d·wk^{-1} because a research assistant was present for their walking sessions. In this current study, the participants were asked to achieve 10,000 steps per day on their own. This may have contributed to the women not achieving the weight loss goal for this study.

There is limited research on the effects of exercise or physical activity on BMD in women during the postpartum period. Little and Clapp (17) compared changes in BMD between women who reported exercising at least 3 d·wk^{-1}, for at least 20 min per session with those who reported not exercising from 2 to 14 wk postpartum. They reported BMD changes during lactation to be similar in both groups. We observed different results in our previous study where lactating women were randomized at the fourth week postpartum to either an exercise group (45 min of walking plus 3 d·wk^{-1} of resistance training) or control group for 16 wk (19). The exercise group lost significantly less lumbar spine BMD compared with the control group (-4.8% vs -7.0%, respectively). The decline in lumbar BMD was similar in the intervention group of this present study; however, the control group lost less lumbar spine BMD compared with the previous study (-3.7% vs 7.0%) (19). The difference may be attributed to the heavier weight of the women in this study (28.0 vs 24.8 kg·m^{-2}, respectively). Previous studies have shown a positive relationship with BMI and BMD (4). In addition, the minimal care group for this present study decreased their energy intake by 171 kcal. This was less than our previous study control group who reduced their intake by 422 kcal (19). Greater energy restriction without exercise may have caused a greater loss of lumbar spine BMD.

A study duration of 16 wk was chosen for this study to allow for a full cycle of bone turnover to occur. With the onset of lactation, the bone turnover cycle is accelerated from the usual four to 8 months to 3–4 months (12). In addition, around 4–6 months postpartum introduction of foods usually begins for the infants. The time frame for this study allowed for measurement of the greatest bone turnover during early lactation when the mother's breast milk provided the sole source of nutrition to the infant.

The peak loss of trabecular bone (lumbar spine and hip) during lactation is around 1%–3% per month compared with a 1%–3% bone loss per year in postmenopausal women with osteoporosis (13). Studies in overweight/obese postmenopausal women (not using hormone replacement therapy) have shown no significant effect of energy restriction and weight loss when combined with weight bearing exercise on bone, specifically the lumbar spine (29, 31). Other studies have reported higher intakes of protein (>1 g·kg^{-1} body weight) and calcium (>1000 mg·d^{-1}) consumption to be protective of bone and fat-free mass during periods of energy restriction and weight loss (27). In the current study, protein (1.1 g·kg^{-1}) and calcium intake (1007 mg·d^{-1}) for the intervention group was at the protective levels reported in the above studies.

The intervention group failed to achieve 10,000 steps per day and, on average, walked only 4838 steps per day. In a survey of 200 men and women, the average daily steps were 5210 for American women, and the higher the BMI (overweight to obese), the lower the average steps (35). When steps were classified into activity levels, <5000 steps was considered to be sedentary (34). A purposeful walk was needed to achieve 10,000 steps per day. Similar to previous studies investigating barriers to physical activity among pregnant and postpartum women (26), participants in the current study reported that bad weather, lack of time, and no childcare were the main reasons for the low number of steps recorded.

Compliance to the resistance training program was much greater than for the daily steps intervention primarily because a research assistant was present for at least one if not all three strength sessions each week. The high compliance was reflected in strength being significantly improved in the intervention group compared with the minimal care group. In addition, the resistance program was designed to take no more than 20–30 min or could be done one set or exercise at a time allowing for flexibility around childcare.

Prolactin concentrations are high during the early postpartum period and decline as lactation continues (15, 32). The prolactin concentrations in this study were elevated at baseline but declined during the 16 wk, which was expected. At baseline, the estradiol concentrations were still elevated from pregnancy, but by end point, estradiol concentrations decreased to concentrations similar to the luteal phase. Krebs et al. (15) reported similar concentrations of prolactin and estradiol, with lumbar spine bone loss, in a longitudinal study of lactating women.

In their study, prolactin concentrations decreased from approximately 140 to 50 $\mu g \cdot L^{-1}$ and estradiol concentrations decreased from 300 to 100 $pmol \cdot L^{-1}$ during 2–20 wk postpartum. They reported that these changes in prolactin and estradiol concentrations corresponded to a 4% loss in lumbar spine BMD. The declines in prolactin and estradiol concentrations and in lumbar spine BMD were similar in our study.

Studies in eumenorrheic women have consistently shown increased exercise-induced GH output in response to either acute aerobic or resistance exercise of varying intensities and durations (8, 14). Although our intervention included both aerobic and resistance exercise training, our assessment of exercise-induced GH output included only acute resistance (1RM) exercise testing. Similar to eumenorrheic women, we observed an increase in the acute resistance exercise-induced GH output in the women who participated in the intervention, but we did not observe this response in the minimal care group. Although both groups of women completed acute 1RM testing, the women in the intervention group lifted considerably more weight at the end point assessment compared with the minimal care group (Table 4). Thus, the women in the intervention group not only lifted more weight, but they had considerably more trials to get to their 1RM and consequently, completed more total work during the acute exercise testing. Exercise studies that have used shorter exercise sessions, such as repeated sprint exercise sessions, have shown that total work completed influences the total GH output in response to exercise (33).

Because GH is a pulsatile hormone, the most accurate reflection of exercise-induced GH output would include GH profiles with blood samples taken every 10 min and at least 30 min (three samples) of baseline sampling before exercise. We had considerable variation in the preexercise GH concentration between groups, and this is likely a reflection of the fact that we sampled GH during a peak in some women and during nadir in other women. Exercise has been shown to circumvent the normal GH feedback loop (40); thus, as was observed in the current study, postexercise GH values are likely to be more consistent. However, given the population included in the current study, the time burden on the participants would have been overwhelming. A previous study investigating the GH response to acute moderate intensity aerobic exercise in postpartum women (14 wk) used a single preexercise - postexercise blood sample and reported consistent increases in GH output from before to after exercise (5). However, the women included in this study were considerably more active (4 $d \cdot wk^{-1}$, average aerobic session lasting 50 min, >5 yr of training) than the women in the current study, and the exercise stimulus was greater (30 min of treadmill walking at 65% of predicted HR_{max}). These two factors may have contributed to the more consistent elevations in GH output after exercise.

Chronic aerobic training has been shown to increase GH secretion and amplify pulsatile release of GH at rest in women if some of their training occurred at intensities above lactate threshold (39). The women in this study trained at intensities below lactate threshold for both aerobic and resistance exercise, which may have contributed to a lack of change in basal GH concentration.

These results suggest moderate energy restriction, walking, and resistance training are safe methods for weight loss in overweight fully breast-feeding women with no adverse effects on BMD and infant growth. The intensity of the exercise intervention in this study may have been below the threshold to elicit a change in basal concentrations of GH. Further research is needed to examine the effects of the intensity, duration, and frequency of exercise on body composition, bone density, and hormones in normal and overweight lactating women.

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