Changes in Bone Mineral Content in Obese Dieting Women

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Significant reductions in total-body bone mineral density (BMD) have been reported in obese women who consume very–low-calorie diets. A reduction in bone mass is highly correlated with an increased risk of osteoporosis. The present study investigated whether strength training would prevent such reductions in dieters. Twenty-one healthy obese women weighing (mean ± SD) 91.1 ± 9 kg and aged 38 ± 9 years were randomly assigned to receive either diet alone or diet plus resistance training. Both groups consumed a 925-kcal/d portion-controlled diet for the first 16 of 17 weeks and a 1,000 to 1,500-kcal/d balanced deficit diet thereafter. Bone mineral content (BMC), BMD, fat-free mass (FFM), and fat mass were measured with dual-energy x-ray absorptiometry (DEXA) before and after 24 weeks of dieting. No significant changes in total-body or lumbar spine BMC and BMD were observed in either condition at the end of treatment. However, both groups demonstrated a significant loss of both BMC and BMD in the femoral neck and greater trochanter. Diet plus resistance training was not associated with a significantly better outcome on either of these measures versus diet alone. The results suggest that increasing the energy content of very–low-calorie diets to 925 kcal/d may prevent the loss of total BMD, but not the loss from the femoral neck and greater trochanter. These findings raise a concern in light of the high frequency of dieting in American women.

OSTEOPOROSIS is a serious health problem in postmenopausal women. Reductions in bone mass in this population are highly correlated with fractures,[1] of which hip fractures account for the greatest proportion of deaths,[2] disabilities,[1,2] and medical costs. Methods used to prevent (or reverse) bone loss have included hormone replacement,[2] antiresorber medications,[1,2] bone formation drugs,[1,2] nutritional intervention,[2] and, most recently, high-intensity strength training.[3,4] This last intervention has been shown to increase bone formation in both elderly women and men.

Obesity also appears to protect against the development of osteoporosis.[5] Obese women, as compared with lean, have a significantly higher bone mineral density (BMD) in the femur and lumbar spine and a significantly lower rate of hip fracture.[6-8] However, dieting—the principal treatment for obesity—may be associated with a significant reduction in total-body BMD, as reported by two investigations that used diets providing 405 to 452 kcal/d.[7,9] This is cause for concern given the millions of obese, as well as non-obese, women who diet regularly in this nation.

This study investigated changes in BMD in significantly obese women who consumed a diet of 925 to 1,500 kcal/d for 24 weeks. We hypothesized that subjects who participated in a vigorous program of resistance training would achieve significantly better preservation of total-body BMD than women treated by diet alone. We similarly anticipated that the former subjects would achieve better preservation of BMD in the femoral neck, greater trochanter, and lumbar spine—areas that were regionally scanned in this study to increase the accuracy of measurement.

SUBJECTS AND METHODS

The subjects were 21 obese women whose characteristics are summarized in Table 1. They were recruited to participate in a 24-week weight reduction study. One subject in each of the two treatments did not complete week 24. Before treatment, all subjects underwent an extensive medical evaluation that included a history and physical examination, electrocardiogram, biochemical profile, tests of thyroid function, and assessment of psychological status.[10] Exclusion criteria included a recent myocardial infarction or evidence of cardiac abnormalities; a history of cerebrovascular, kidney, or liver disease; cancer; type I or II diabetes; bulimia nervosa; or significant psychiatric illness.[11,12] No subjects were taking medications known to affect metabolism or skeletal health. Thirteen subjects were premenopausal, four were perimenopausal, and four were postmenopausal. Three subjects were using oral contraceptives, and four were on estrogen therapy. We did not select or exclude subjects on the basis of baseline menopausal status, because Jensen et al.[9] found no differences in bone mineral loss among premenopausal, perimenopausal and postmenopausal women who were undergoing weight loss. Subjects gave informed consent to participate in the study, which was approved by the University of Pennsylvania's Committee on Studies Involving Human Beings.

Procedures

Subjects were randomly assigned to one of two conditions: (1) diet alone (n = 9) or (2) diet plus resistance training (n = 12). Table 1 shows that there were no significant differences between treatment groups in baseline age, height, or weight. All subjects attended weekly 90-minute group treatment sessions for 24 weeks. Sessions were led by clinical psychologists who followed a modified version of the Optifast core program[12] that provided instruction in the modification of eating and exercise habits.

Diet

Participants were asked to maintain their normal dietary intake during an initial baseline week. During weeks 2 to 17, they were provided a diet of approximately 900 to 925 kcal/d that consisted of four servings daily of a liquid meal replacement combined with a dinner entrée and two cups of salad. Each serving of the liquid diet provided 150 kcal, 15 g protein, 11 g carbohydrate, 5 g fat, 200 mg calcium, 200 mg phosphorus, and 80 IU vitamin D. Each shelf-stable entrée provided approximately 300 kcal, 20 g protein, about 40 g carbohydrate, and 7 g fat (Healthy Recipes; Sandoz Nutrition, Minneapolis, MN). No vitamin or mineral supplements were given to the subjects.

At week 18, subjects decreased their consumption of the liquid diet

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Submitted January 19, 1996; accepted January 31, 1997.

Supported by National Institute of Mental Health Grants No. RO1-MH45491-03 and KO2-MH00702-06 (both to T.A.W.).

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0026-0495/97/4608-0002$03.00/0

Table 1. Characteristics (mean ± SD) of the Subjects Under Conditions of Diet Only and Diet Plus Resistance Training

Variable	Diet Only		Diet + Resistance Training	
	Baseline (n = 9)	24 Weeks (n = 8)	Baseline (n = 12)	24 Weeks (n = 11)
Age (yr)	38.1 ± 7.6	—	41.1 ± 11.1	—
Height (cm)	164.8 ± 3.7	—	161.4 ± 7.3	—
Weight (kg)	91.3 ± 8.9	71.9 ± 9.7†	91.0 ± 9.1	74.4 ± 11.7†
FFM (kg)	46.4 ± 4.5	43.6 ± 4.8†	44.0 ± 4.5	42.7 ± 3.8*
Fat mass (kg)	44.9 ± 8.7	28.3 ± 10.6†	47.0 ± 4.9	31.7 ± 8.7†

*Significantly ($P < .05$) different from baseline.
†Significantly ($P < .01$) different from baseline.

while increasing consumption of conventional foods. The liquid diet was eliminated first at breakfast, followed by the afternoon snack, and then lunch. This occurred at weeks 18, 19, and 20, respectively, at which time the prescribed caloric intake was 1,053, 1,150, and 1,250 kcal/d, respectively. Subjects were asked to consume a diet of 1,250 to 1,500 kcal/d thereafter (ie, weeks 21 to 24). This refeeding protocol was supervised by a registered dietitian who was a co-leader of group sessions for 10 weeks and met individually with patients once during weeks 21 to 23 to help plan menus and identify the caloric intake needed to achieve weight stability. Compliance to the diet was monitored by daily food records; these diet diaries were reviewed by group leaders at each weekly meeting.

Exercise Conditions

Diet alone. Subjects in the diet-alone condition (n = 9) did not participate in a supervised exercise program. In addition, they were instructed not to engage in any type of resistance training or programed exercise. Investigators reviewed subjects' activity logs weekly to ensure that they did not engage in excessive life-style activity (ie, walking or climbing stairs).

Diet plus resistance training. Subjects on the diet plus resistance training (n = 12) participated in three supervised exercise sessions per week (on nonconsecutive days) for 24 weeks. They engaged in calisthenics and used Nautilus (Independence, VA) and Cybex (Ronkonkoma, NY) gym equipment. The circuit of exercises focused on training large muscle groups. At week 1, subjects were familiarized with the equipment. At week 2, they performed one set of the bench press, latissimus pull-down, chest fly, shoulder press, leg extension, leg curl, leg press, hip extension, arm curls and extensions, sit-ups, and back extension. Subjects performed all exercises with a resistance that allowed them to make at least eight repetitions but not more than 12. Initial workouts lasted about 30 minutes, which included a 5- to 10-minute warm-up and cool-down period. From weeks 3 to 14, an additional set of exercises were added to the routine until two sets of each exercise were completed at each workout. Thus, by the end of week 14, the exercising subjects spent approximately 50 minutes in resistance training. Workout time was held constant between weeks 14 and 24, but resistance was increased whenever subjects were able to perform more than 12 repetitions for two consecutive workouts.

Of the total of 72 exercise sessions over 24 weeks, subjects attended a mean of 61.4 ± 9, equal to 85.3% ± 12.4% of the workouts. All subjects attended a minimum of two sessions per week for 24 weeks.

During the first week of treatment, subjects practiced and learned to perform one-repetition maximal lifts. This practice period was implemented to prevent interpretation of the initial neural adaptations[13] as strength gains. At the beginning of week 2, baseline one-repetition maximal lifts were established for the chest press, latissimus pull-down, leg press, leg extension, and leg curl. The maximal lifts were repeated monthly and at the end of 24 weeks of treatment. A total-body strength index was calculated by summing the five maximal lifts, and a lower-body strength index was calculated by summing the three lower-body lifts. Total- and lower-body strength increased significantly ($P < .001$) by 36.6% ± 12% and 31.1% ± 12%, respectively.

Dependent Measures

BMD. Dual-energy x-ray absorptiometry (DEXA) (model DPX; Lunar Radiation, Madison, WI) was used to scan the total body, anteroposterior lumbar spine (L2 to L4), and proximal femur; the slow scan speed was used. Lunar version 3.6 DPX software programs were used for all BMD and bone mineral content (BMC) determinations. The same technician, scanner, and software program were used for baseline and week 24 measurements. The technician was blinded to the intervention. Since system precision is an important variable, 11 scans of a hip phantom were taken over a 9-month period to assess the exactness of the scanner. The average of 11 scans was 1.212 ± 0.0047 g/cm^2. The coefficient of variation was calculated (SD × 100/mean value) as 0.38%, which is consistent with or exceeds the precision reported by other investigators.[3,7] To examine the in vivo variability of our scanner, we scanned five volunteers in the morning and rescanned them later in the day. Their hip density ranged from 1.089 to 1.600 g/cm^2. The average values for the first and second scans were 1.287 ± 0.216 and 1.283 ± 0.209, respectively. We computed an average difference of 0.0036 g/cm^2, or a −0.22% difference between the first and second in vivo scans.

Weight and body composition. Body weight was measured at each visit on a balance-beam scale with subjects in shorts and a t-shirt. Height was measured using a medical-grade stadiometer. Fat and bone-free lean soft tissue were derived from the total-body DEXA scans. Hence, the fat-free mass (FFM) reported in this investigation included all lean tissue except bone mineral.

Statistics

A repeated-measures ANOVA was used to examine changes in the dependent variables. Pearson product-moment correlations were used to examine the relationship between baseline measures of body composition and BMC and between changes in these variables at the end of treatment. Based on the significant bone formation reported in strength-trained adults, as well as the reduction in bone density observed in dieting women, we calculated that randomly assigning 20 subjects to one of two treatment groups would provide ample power to detect differences.[14]

RESULTS

Weight

Table 1 shows that at the end of 24 weeks, the diet-alone group lost 19.4 kg and the resistance-training group lost 16.6 kg. The diet-alone subjects lost 16.6 kg fat and 2.8 kg FFM, while resistance-training subjects lost 15.3 kg fat and 1.3 kg FFM. No significant differences were observed between groups on any of the body composition measures.

BMC/BMD

There were no significant reductions in total-body, lumbar, or Ward's-triangle BMC in either group at the end of 24 weeks. However, repeated-measures ANOVA showed that the BMC of both the femoral neck and greater trochanter declined significantly (both $P < .05$) with weight loss (Table 2). Reductions in femoral neck BMC of 13.3% (0.68 g) and 7.8% (0.46 g) were observed in the diet-alone and resistance-training groups, respectively. BMC in the greater trochanter was reduced by 7.2% (0.95 g) and 13.1% (1.86 g) in the two groups, respec-

Table 2. Total and Regional BMC and BMD (mean ± SD) of Subjects on Diet Only and Diet Plus Resistance Training

	Diet Only			Diet + Resistance Training		
Variable	Baseline (n = 9)	24 Weeks (n = 8)	% Change	Baseline (n = 12)	24 Weeks (n = 11)	% Change
Total						
BMC (g)	2,781 ± 416	2,822 ± 396	1.2 ± 3.8	2,765 ± 344	2,707 ± 376	−0.6 ± 7.2
BMD (g/cm²)	1.22 ± 0.1	1.23 ± 0.1	0.8 ± 2.8	1.21 ± 0.1	1.22 ± 0.1	1.0 ± 3.5
Lumbar						
BMC (g)	52.3 ± 11	52.8 ± 12	0.8 ± 1.9	53.7 ± 10	53.7 ± 8	0.7 ± 5.6
BMD (g/cm²)	1.29 ± 0.2	1.28 ± 0.2	1.2 ± 1.8	1.29 ± 0.1	1.30 ± 0.1	0.7 ± 4.4
Femoral Neck						
BMC (g)	5.07 ± 0.84	4.39 ± 1.48*	−13.3 ± 19.8	5.30 ± .96	4.84 ± 1.13*	−7.8 ± 12.4
BMD (g/cm²)	1.09 ± 0.2	1.03 ± 0.2*	−2.9 ± 3.2	1.12 ± 0.1	1.06 ± 0.1*	−3.9 ± 5.2
Trochanter						
BMC (g)	11.78 ± 2.9	10.85 ± 2.4*	−7.2 ± 9.9	12.80 ± 2.3	10.48 ± 2.1†	−13.1 ± 14.0
BMD (g/cm²)	0.88 ± 0.2	0.87 ± 0.2	−1.4 ± 4.9	0.93 ± 0.1	0.87 ± .01†	−3.8 ± 3.4
Wards Triangle						
BMC (g)	2.33 ± 0.5	2.61 ± 0.7	12.0 ± 13.7	2.46 ± 0.7	2.58 ± 0.9	3.24 ± 16.6
BMD (g/cm²)	0.95 ± 0.2	0.95 ± 0.2	0.16 ± 6.7	1.00 ± 0.2	0.93 ± 0.2	−5.2 ± 7.4

*Significantly ($P < .05$) different from baseline.
†Significantly ($P < .01$) different from baseline.

tively. There were no significant differences between groups on either measure.

BMD of the femoral neck and greater trochanter did decline significantly (both $P < .05$) during the 24-week program (Table 2 and Fig 1). Reductions in femoral neck BMD of 2.9% (0.02 g/cm²) and 3.9% (0.04 g/cm²) were observed in the diet-alone and resistance-training groups, respectively. There were no significant differences between groups on either measure. Repeated-measures ANOVA also showed that there were no significant reductions in total-body, lumbar, and Ward's-triangle BMD in either group after the 24-week weight reduction program. Five of 21 patients (two diet-alone and three resistance-trained) had no change or slight increases in femoral neck BMC.

Body Composition and BMC

Table 3 shows the relationship between baseline weight, fat, FFM, and total and regional BMC. Positive correlations ($P < .05$) were observed between FFM and total and femoral neck BMC. Thus, subjects with greater FFM had higher BMC. Total-body BMC was also positively correlated ($P < .01$) with leg press strength. Changes in body composition did not correlate significantly with changes in BMC or BMD.

DISCUSSION

This study found no significant reductions in total-body BMD in obese women who lost approximately 18 kg in 24 weeks by consuming a 925 to 1,500-kcal/d diet. These findings stand in contrast to those of Compston et al[7] and Jensen et al,[9] who observed significant losses of total-body BMD in subjects who consumed diets providing 405 kcal/d and 452 to 1,000 kcal/d, respectively. Subjects in these two studies lost 15.6 and 12.3 kg, respectively. Thus, the present results suggest that increasing the energy content of reducing diets may prevent the loss of total-body BMD. A randomized trial is needed to test this hypothesis.

This is the first study to assess the effects of weight loss on bone mineral in the lumbar spine and the proximal femur by using regional scans. We observed no significant changes in the lumbar region. However, statistically significant reductions

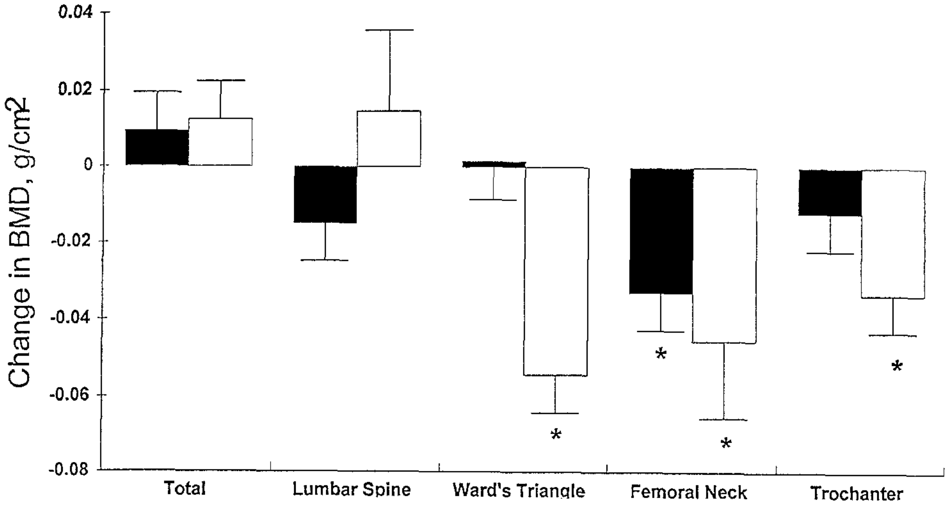

Fig 1. Changes in bone after a 24-week diet program: (■) diet only, (□) diet plus resistance training. *Values are the mean ±* SE for individual changes in BMD. *Significantly ($P < .05$) different from baseline.

Table 3. Correlations Between Baseline Weight, Fat Mass, FFM, and Leg Strength and BMC in Obese Women (N = 21)

BMC	Weight (kg)	Fat Mass (kg)	FFM (kg)	Leg Strength
Total	.19	.06	.43*	.70†
Femoral neck	.35	.12	.45*	.11
Lumbar	.20	.17	.17	−.24
Ward's triangle	.27	.07	.38	.01

*Significantly correlated ($P < .05$).
†Significantly correlated ($P < .01$).

were observed for BMC and BMD of both the femoral neck and greater trochanter. These findings extend those of Jensen et al,[9] who reported greater losses of BMD in the trunk and legs based on analysis of whole-body scans. Regional scans provide far greater resolution than whole-body scans.

Jensen et al[9] have suggested that weight loss leads to bone loss as a result of reducing weight-bearing stress on the bone, since increased bone formation is directly related to the mechanical loads placed on it.[15] Thus, we hypothesized that our resistance-trained subjects, whose lower-body exercises placed high weight loads on the hip joint, would have a sparing of bone mass in the femoral neck significantly better than that of subjects treated by diet alone. This hypothesis was not confirmed. Studies with larger sample sizes (and thus more statistical power) are needed to rule out the possibility of a type II error in the present study. Future research should examine whether more percussive exercise such as aerobic dancing or brisk walking can help to prevent the adverse changes in the femur that we observed. It was of interest that baseline total-body BMC was strongly correlated with baseline leg strength (r = .70) and FFM (r = .43).

We do not know why femoral neck and greater trochanter BMD but not lumbar or Ward's-triangle BMD decreased with weight loss. Interestingly, Ryan et al[3] found that high-intensity strength training preferentially increased bone density of the femoral neck in elderly men, with no changes in total-body or lumbar bone density. Leslie and Nance[16] found that spinal cord–injured men demonstrated significant demineralization in the hip compared with a group of men with endocrine disorders, suggesting that the selective loss of bone in the hip may be related to disuse. Sowers et al[17] reported that low muscle content in the hip area was related to low BMD in that area in young adult women. However, in the present study, regional soft tissue analyses from total-body DEXA scans revealed no significant loss of lean tissue in the legs of either treatment group. It is unlikely that malnutrition was responsible for the decline, since subjects received in excess of 800 mg calcium, 800 mg phosphorus, and 400 IU vitamin D each day.

The full clinical significance of bone loss in dieting obese women remains to be determined. Markedly obese women have greater BMC than average-weight women.[5,7,9] Thus, even with a dieting-induced decline, BMD in the former subjects may well be in the "normal" range after weight reduction. Moreover, when weight is regained, as it frequently is after dieting, bone appears to be regained,[7] although it is not known whether the trabecular bone is fully restored. Long-term investigations are needed to examine the changes in bone density in obese subjects who do and do not seek weight reduction. Studies of anorectic women have revealed significant losses of both cortical and trabecular bone.[18] Weight regain and the restoration of menses in these patients have been found increase bone mass, although final bone mass remains at less than normal levels for age-matched women.[19,20]

It has recently been reported that over 40% of American women are voluntarily trying to lose weight, compared with only 23% of American men.[21] The high rate of dieting in women may be cause for concern, since osteoporosis is a serious problem in older women. Persons at greatest risk of the possible adverse effects of dieting on bone mass would appear to be adolescent girls and young women of near-normal weight. Many of these individuals diet frequently and aggressively in pursuit of a thin ideal, which may prevent optimal or peak bone formation. Their consumption of suboptimal diets low in calcium and other essential vitamins and minerals, as well as their loss of body weight and potentially of bone mass, could substantially increase the later risk of developing osteoporosis. Further research is needed to examine this possibility to determine the optimal regimen of diet and exercise for obese individuals seeking weight reduction.

REFERENCES

1. Kanbara Y, Mizuno K, Hirohata K, et al: A comparison of the bone mineral density of the vertebral bodies and the hip in elderly females with hip fractures. Kobe J Med Sci 38:21-36, 1992
2. Keil DP: New strategies to prevent hip fracture. Hosp Pract (Off Ed) 29:47-54, 1994
3. Ryan AS, Treuth MS, Rubin MA, et al: Effects of strength training on bone mineral density: Hormonal and bone turnover relationships. J Appl Physiol 77:1678-1684, 1994
4. Conroy MA, Kraemer WJ, Maresh CM, et al: Adaptive responses of bone to physical activity. Med Sci Nutr Health 1:64-74, 1992
5. Grisso JA, Kelsey JL, Strom BL, et al: Risk factors for hip fracture in black women. N Engl J Med 330:1555-1559, 1994
6. Hyldstrup L, Andersen T, McNair P, et al: Bone metabolism in obesity: Changes related to severe overweight and dietary weight reduction. Acta Endocrinol (Copenh) 129:393-398, 1993
7. Compston JE, Laskey MA, Croucher PI, et al: Effect of diet-induced weight loss on total body bone mass. Clin Sci 82:429-432, 1992
8. Albu J, Smolowitz JL, Lichtman S, et al: Composition of weight loss in severely obese women: A new look at old methods. Metabolism 41:1068-1074, 1992
9. Jensen LB, Quaade F, Sorensen OH: Bone loss accompanying voluntary weight loss in obese humans. J Bone Miner Res 9:459-463, 1994
10. Wadden TA, VanItallie TB, Blackburn GL: Responsible and irresponsible use of very–low-calorie diets in the treatment of obesity. JAMA 263:83-85, 1990
11. Wadden TA, Foster GD: Behavioral assessment and treatment of markedly obese patients, in Wadden TA, VanItallie TB (eds): Treatment of the Seriously Obese Patient. New York, NY, Guilford, 1992, pp 290-330
12. Wadden TA, Foster GD, Letezia KA, et al: A multi-center evaluation of a proprietary weight reduction program for the treatment of marked obesity. Arch Intern Med 152:961-966, 1992
13. Zatsiorsky VM: Science and Practice of Strength Training. Champaign, IL, Human Kinetics, 1995, pp 76-81

14. Kraemer HC, Thieman S: How Many Subjects? Statistical Power in Research. Newbury Park, CA, Sage, 1990, pp 103-111

15. Nelson ME, Fiatrone MA, Morganti CM, et al: Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures: A randomized controlled trial. JAMA 272:1909-1914, 1994

16. Leslie WD, Nance PW: Dissociated hip and spine demineralization: A specific finding in spinal cord injury. Arch Phys Med Rehabil 74:960-964, 1993

17. Sowers MF, Kshirsagar A, Crutchfield MM, et al: Joint influence of fat and lean body composition compartments on femoral bone mineral density in pre-menopausal women. Am J Epidemiol 136:257-265, 1992

18. Klibanski A, Biller BMK, Shoenfeld DA, et al: The effects of estrogen administration on trabecular bone loss in young women with anorexia nervosa. J Clin Endocrinol Metab 80:898-904, 1995

19. Drinkwater BL, Nilson K, Ott S, et al: Bone mineral density after resumption of menses in amenorrheic athletes. JAMA 256:380-382, 1986

20. Klibanski A, Greenspan SL: Increase in bone mass after treatment of hyperprolactinemic amenorrhea. N Engl J Med 315:542-546, 1986

21. Horm J, Anderson K: Who in America is trying to lose weight? Ann Intern Med 119:672-676, 1993