Effect of diet-induced weight loss on total body bone mass

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1. Total body areal bone mineral density was measured by dual-energy X-ray absorptiometry in eight women before and 10 weeks after a very-low-calorie diet [405 kcal (1701 kJ)/day].

2. The mean weight loss of 15.6 kg was accompanied by a statistically significant reduction in total body bone mineral density from 1.205 ± 0.056 to 1.175 ± 0.058 g/cm² (mean ± SD, P<0.005).

3. After cessation of the diet, weight gradually increased and by 10 months was similar to baseline values. Total body bone mineral density also increased after stopping the diet and mean values obtained 10 months after the diet did not differ significantly from initial values. Throughout the study total body bone mineral density values in all subjects were well within the range reported for normal subjects.

4. These data indicate that diet-induced weight loss is associated with rapid bone loss, subsequent weight gain being accompanied by increases in bone mass. Further studies are required to establish the clinical significance of these findings and, in particular, the skeletal distribution of bone loss.

INTRODUCTION

Body size is an important determinant of bone mass [1] and there is evidence that frame size, muscularity and adiposity all have independent effects on the skeleton [2]. Higher areal bone mineral density (BMD) values in the femur and lumbar spine have been reported in obese premenopausal women than their non-obese counterparts [3], while low body weight is associated with low bone mass and an increased risk of fragility fracture [4].

Little is known about the effects of diet-induced weight loss on bone mass in obese subjects. Low bone mass and increased fracture risk have been reported in anorexia nervosa [5–9] and surgical procedures for weight reduction, such as jejuno-ileal bypass, gastroplasty and biliopancreatic bypass, are also associated with some reduction in bone mass, although this finding has not been invariable [10–15]. In this study we report the effects of diet-induced weight loss and subsequent weight gain on total body bone mass.

EXPERIMENTAL

Subjects and methods

Thirteen women, aged 37–60 years (mean ± so 47.2 ± 5.9 years), were recruited into the study. Their weight ranged from 65.6 to 108.2 kg (mean 89.6 kg) and their body mass index, calculated as weight/height², ranged from 22.8 to 43.2 kg/m² (mean 32.2 kg/m²). For 10 days before starting a very-low-calorie diet (VLCD), the women were put on a diet containing 1600 kcal (6720 kJ) and 68 g of protein/day. Immediately after this 10 day period the VLCD was commenced [Cambridge Diet extra containing 405 kcal (1701 kJ), 45 g of carbohydrate and 42 g of protein/day] and this was continued for 10 weeks. Total body bone mass was assessed during the 10 days before starting the VLCD, and subsequently at 11 weeks (during the final week of the VLCD), 23 and 57 weeks. The first two measurements were performed in 12 of the subjects, whereas nine completed all four measurements. One subject missed both the third and final measurements and two missed only the final measurement. One women had silicone breast implants between the second and third measurements and in her case the final two measurements were excluded from the analysis. Nine of the women were peri- or post-menopausal.

Total body BMD was assessed by dual-energy X-ray absorptiometry using the Lunar dual-energy absorptiometer [16]. The precision of paired measurements in obese subjects (n = 13) is 0.7% and 1.4% (coefficients of variation) for whole-body BMD and mineral content, respectively. In normal subjects (n = 28) the corresponding values are 0.7% and 0.9%. The coefficient of variation was calculated as follows:

\[ \text{Coefficient of variation} = \frac{\text{SD} \times 100}{\text{mean value}} \]

\[ \frac{1}{n} \sum_{i=1}^{n} d_i^2 \]

Key words: bone mineral density, very-low-calorie diet, weight loss.

Abbreviations: BMD, bone mineral density; VLCD, very-low-calorie diet.

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where \( d \) is the difference between duplicates and \( n \) is the total number of determinations.

Differences between mean values were compared by multivariate analysis of variance. The SPSS/PC program used excluded all incomplete records from the analysis, leaving a total of eight subjects in whom all four measurements were performed. Correlations were examined using linear regression analysis.

**Experiments in vitro**

The effect of increased soft tissue thickness on measurements of bone mineral content and BMD was assessed by using a plastic tank containing an aluminium phantom, on top of which one or two layers of lard (3.5 and 7.0 cm, respectively) were arranged. Known amounts of water, which simulates fat-free tissue, were added to give a range of total depths up to 22 cm. The phantom was scanned five times at each depth of water using the whole-body mode and expressed as a percentage of values obtained using the spine model. These experiments are described in greater detail elsewhere [17].

**RESULTS**

**Experiments in vivo**

Fig. 1 shows the changes in total body BMD in the eight subjects who underwent all four measurements. Over the period of dieting, the mean weight decreased from 93.6 ± 11.7 to 78.0 ± 9.7 kg (mean ± SD); subsequently, the mean weight increased, values at 23 and 57 weeks being 82.6 ± 8.5 and 89.7 ± 13.1 kg, respectively. Total body BMD decreased from 1.205 ± 0.056 to 1.175 ± 0.058 g/cm² over the period of dieting (\( P < 0.005 \)); values at 23 and 57 weeks were 1.177 ± 0.058 and 1.206 ± 0.06 g/cm², respectively. The mean difference (95% confidence intervals) between the second and first total body BMD value was -0.03 (-0.047 to -0.014) g/cm² and between the final and first measurement it was +0.001 (+0.01 to -0.009) g/cm².

Total body bone mineral content decreased from 3170 ± 390 to 3025 ± 356 g over the period of dieting (\( P < 0.01 \)). Subsequently, at 23 and 57 weeks, the mean values increased to 3094 ± 346 and 3104 ± 378 g, respectively. The mean difference (95% confidence intervals) between the second and first total body BMD value was -145 (-225.1 to -64.8) g and between the final and first measurement it was -65.9 (-140.7 to +8.9) g. There was no statistically significant difference between the mean values obtained at the fourth and first measurements.

Linear regression analysis revealed a significant correlation between the change in weight and in total body BMD over the period of dieting in the 12 subjects who had the first two measurements (\( r = 0.669, P < 0.01 \), Fig. 2). When values from all measurements were included, there was a significant positive correlation between total body BMD and weight (\( r = 0.536, P < 0.001 \)). This correlation was significant both between subjects (\( r = 0.532, P < 0.05 \)) and within subjects (mean \( r \) value = 0.682, \( P < 0.001 \)).

**Experiments in vitro**

At depths below 9 cm, one layer of fat placed on the phantom did not significantly affect bone mineral content and area values. At depths above 9 cm, both bone mineral content and area increased, resulting in a decrease in BMD values between 14 and 22 cm. At 22 cm the bone mineral content was 140%, the area was 170% and the BMD was 82.6% of the spine mode value. For two layers of fat, bone mineral content and area were overestimated at all depths, whereas BMD was consistently underestimated, the discrepancies being quantitatively similar to the experiments with one layer of fat [17].

**DISCUSSION**

In this study diet-induced weight loss was associated with a significant reduction in total body BMD over a period of 11 weeks. Subsequently, over the follow-up
period of approximately 10 months, most women approached their pre-diet weight and bone mass returned to near baseline values. In all cases before, during and after dieting, BMD values were well within the reference range obtained from a sample of 138 healthy female subjects and the normal reference data recently reported [18].

Previous studies of bone mass in obese subjects have mostly been confined to regional measurements, with both normal and increased values being reported [3, 12, 13, 15, 19–22]. The relationship between body size and bone mass is complex and probably reflects bone size rather than true BMD. In absorptiometric techniques, values are expressed as an areal density, in g/cm²; however, the third dimension of size, depth, is not assessed and thus, as observed in this study, areal density values still show some dependence on body size. If true BMD is measured, as in quantitative computed tomography, the effect of bone size is eliminated and no relationship can be demonstrated between BMD and body size [23]. Thus it is possible that in obese subjects, in whom bone size is increased, areal BMD values may overestimate true BMD.

Measurement of bone mass in obese subjects presents technical problems when absorptiometric techniques are used because of the thickness of soft tissue present, which reduces the proportion of X-rays surviving attenuation and interferes with bone edge detection. However, our phantom experiments demonstrated that increasing soft tissue thickness is associated with decreasing BMD values [17], a finding consistent with data reported in the forearm [13]; in contrast, bone mineral content and area values were overestimated at thicknesses greater than 10 cm. If the observed changes in bone mineral content and BMD associated with dieting were artefactual and occurred entirely as a result of changes in soft tissue thickness and associated variations in the accuracy of bone edge detection, the decrease in bone mineral content would have been accompanied by an increase in BMD, as in the phantom experiments. Similarly, during weight gain an increase in bone mineral content and a decrease in BMD would be anticipated. The demonstration, in our study, that bone mineral content and BMD changed in the same directions during weight loss and subsequent weight gain provides strong evidence that the observed changes in bone mass were qualitatively genuine, although changes in bone mineral content during weight loss are likely to have been overestimated and those occurring in BMD underestimated. In addition, in one subject with a body weight of 65.6 kg and normal body thickness the decrease in total body BMD after dieting was comparable with that observed in the other obese subjects.

The mechanism of the bone loss observed is unknown. The majority of women in the present study were peri- or post-menopausal, but may still have been capable of some endogenous oestrogen production, particularly in view of their obesity; it is possible that reduced endogenous oestrogen production during weight loss may have played a role. Malnutrition seems unlikely to have been a pathogenic factor in the present study and the calcium intake during the diet, 800 mg/day, makes calcium deficiency an unlikely contributory factor. Finally, there were no large changes in physical activity during the course of the study which could account for the observed changes in bone mass.

The clinical implications of our results require further investigation. Increased bone turnover provides the only possible mechanism of bone loss occurring over such a short time span [24]; this is potentially reversible, providing that remodelling balance is maintained. Since 80% of the skeleton is composed of cortical bone, total body bone mass predominantly reflects cortical rather than trabecular bone mass and it is possible that relatively small changes in total body bone mass may mask larger ones in trabecular bone. Thus regional measurements of bone mass, particularly in the spine and femur, are required to assess more accurately the clinical significance of bone loss associated with weight reduction. Finally, studies are required to determine whether diet-induced bone loss persists when weight loss is maintained after dieting and to establish whether the changes in bone mass reflect a physiological adjustment to the new and more appropriate body weight, as observed with other components of body composition.

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