Changes in bone mineral density associated with dietary-induced loss of body mass in young women

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1. Moderately overweight, premenopausal women were assessed for bone mineral density of the total body, lumbar spine and proximal femur before and after 6 months of modest dietary restriction (minimum 4800 kJ/day). The aim was to evaluate the effect of loss of body mass on bone mineral density.

2. Dietary assessment included two analyses of 3 day weighed food intakes, one before and the other after 4 months of dietary restriction. Energy and calcium intakes were significantly reduced by 27% and 5%, respectively. The change in calcium intake was negatively and significantly related to initial levels of calcium intake.

3. A significant mean loss of 3.4 ± 3.1 kg in body mass was achieved mainly in the first 3 months of the study; it was accompanied by significant losses at 6 months in bone mineral density in the total body of 0.7% and in the lumbar spine of 0.5%. There were no changes in the femur.

4. The change in bone mineral density in the total body was significantly related to the reduced absolute calcium intake, initial bone mineral density and loss of body mass. The change in bone mineral density in the spine was significantly related to the change in calcium intake.

5. These modest losses could be a threat in women with lower bone mineral density, and indicate the importance of maintaining a high intake of calcium during dietary restriction.

INTRODUCTION

A growing body of evidence demonstrates a positive association between bone mineral density (BMD) and body mass. In epidemiological studies, heavy subjects are less susceptible to osteoporotic fracture than their leaner counterparts [1–5], and in cross-sectional studies weak, but significant positive correlations have been reported between body mass and BMD [6–14]. Two recent longitudinal studies in overweight postmenopausal women showed that substantial loss of body mass due to reduced energy intake was associated with a significant loss of total body BMD (TBBMD) [15, 16]. One of these studies was of a severely restricted intake of only 1700 kJ/day. The aim of this study therefore was to find out whether more moderate dieting in younger women, which is widely practised, leading to moderate loss of body mass would be detrimental to the skeleton. The question of whether weight loss could be a confounding influence in studies of the therapeutic effects of drugs or exercise on BMD is also of interest.

METHODS

Subjects

A mailed invitation was addressed to all female employees within a large teaching hospital in the U.K. The entry criteria were: Caucasian, eumenorrheic, at least 12 months post partum, non-pregnant, non-smoker and a body mass index (BMI) between 21 and 30 kg/m² [17]. Any subject who had begun a new form of vigorous exercise, such as jogging, squash or weight training, within the previous 3 months was excluded. The study was approved by the Medical School Ethics Committee, and all subjects gave their informed consent.

Design

Subjects were prescribed an individually tailored reduced energy diet aimed at gradual loss of body mass over a period of 6 months. Targets were ideal body mass for height to within 5% [17]. The recommended restriction therefore varied with the degree to which each subject was overweight. BMD was assessed at the start and at 3 monthly intervals. There was no formal control group in our study since volunteers for a weight loss study are not likely to adhere to the 'no change' requirement of a control group. The loss of body mass was expected to vary since the women started at variable distances from their target and also because of likely variation in adherence to the prescribed diet. This would allow examination of the relation between weight loss and change in BMD. Statistical advice
was sought and, taking into account the sensitivity of the measurement of BMD, a recruited group of 50 women were deemed to confer sufficient power to detect a significant relation at the 5% level.

**Weight loss programme**

Diets were based on the Health Education Council guidelines with a minimum of 4800 kJ/day. The requirement was to adopt a low-fat, high-carbohydrate diet, which included calcium-rich foods (very-low-fat and skimmed varieties of dairy products). Participants were required to avoid excessive intakes of dietary fibre since it inhibits the absorption of essential vitamins and minerals including calcium [18, 19]. Energy restriction via reduction in portion size was emphasized, especially to those already adhering to a low-fat, low-sugar diet. Subjects received a calorie-counting guide [20] to use as a reference for the energy content of foods, and a diary to record body mass, which was measured at the same time of day, weekly throughout the period of study. A senior dietician acted as a consultant and addressed the group at intervals, providing nutritional advice and opportunity for discussion. Once individuals have volunteered for a weight loss programme they begin to change their diet, so measurements of body mass and dietary intake were made as soon as possible. For logistic reasons this meant there was a delay of about 2 weeks before the densitometry measurements were made. Since bone takes 2-3 months to complete a remodelling cycle [21], early changes in BMD due to the intervention would not have been missed.

**Dietary assessment**

Subjects completed two 3 day weighed food records, initially to provide a baseline for subsequent energy reduction, and again after 4 months of the weight loss programme. The record was completed using calibrated scales (EKS 2000; EKS Sales Limited, Letchworth, Herts, U.K.), precision ±2 g, over 3 consecutive days, 2 weekdays and 1 weekend day. All food consumed during this period was required to be weighed and recorded in a food diary. Foods considered impractical to weigh were expressed in convenient household measures or described in terms of portion size (e.g. 1 tablespoon of olive oil) and were subsequently converted to weight using a booklet of food portion sizes [22]. The diets were analysed using the Microdiet software, which is based on standard food tables [23]. The mean of the 3 days was taken as the definitive estimate of daily energy intake (kJ/day), calcium (mg/day), vitamin D (μg/day), phosphorus (g/day), fibre (g/day), protein (g), fat (g) and carbohydrate (g). Also of interest were the relative contributions of protein, fat and carbohydrate (%) to energy intake.

A structured food frequency questionnaire and a diet history were also completed by one interviewer at the beginning in order to obtain more representative data. Information from all three dietary methods was used in diet prescription. The structured food frequency questionnaire for calcium has been used previously [24]. The interviewer asked questions about daily or weekly intakes of 12 different foods known to have a high calcium content, including dairy products, fish, fruit, vegetable and cereal products. A quantified estimate of daily calcium intakes was then derived using standard food tables [23]. The questionnaire has a re-test reliability of 6.9%. The diet history followed standard guidelines for the assessment of dietary intake [25].

Leg extensor power [26] was assessed initially and after 6 months as a marker for changes in habitual physical activity which might affect energy balance or BMD.

**BMD and body composition**

Dual energy X-ray absorptiometry (Lunar DXP-L, software version 1.3; Lunar Corp., Madison, WI, U.S.A.) was used to assess BMD in the lumbar spine (L1-L4, antero-posterior view) and non-dominant proximal femur (neck, Ward's triangle and trochanter), initially and after 6 months. Total body bone mineral content, BMD, and the proportion of fat and lean tissue were measured, initially, after 3 months to check for rapid loss of bone mineral, and finally at 6 months. A medium scan speed was used for all scans, except where tissue thickness in the region of interest exceeded 24 cm and a slow scan speed was then used. Height was measured to the nearest 0.005 m using a free standing stadiometer. Body mass was measured to the nearest 0.05 kg (Marsdens balance scales). BMI was calculated as weight in kg divided by the square of the height in m.

Both calibration and reliability in vivo for the spine and femur have been reported [27]. Reliability for TBBMD and bone mineral content were determined from repeat measurements in 12 individuals (coefficient of variation was 0.6% and 0.9%, respectively). Among women of reproductive capacity the effective dose equivalent is less than 1.0 μS for spine and femoral scans, and less than 0.3 μS for the total body. This may be compared with a mean daily radiation dose of 5.1 μS.

**Analysis**

Data are expressed as means ± SD unless otherwise stated. Student's t-tests for paired means were used to assess differences. Pearson product moment correlations were used to explore simple relations between variables, and two-tailed significance levels were obtained. Stepwise multiple regression analysis was used to find which factors explained the most variance in change in BMD.
RESULTS

The 45 women who completed the study were aged 33 ± 7.0 (range 28-44) years, with height 1.62 ± 0.05 (1.52-1.71) m and an initial BMI (weight in kg divided by the square of the height in m) of 25.6 ± 2.1 (22.3-30.6) kg/m² which exceeds the population mean of 24.4 kg/m² for women aged 25-44 years [28]. Initial values for all variables assessed were on average above age-matched norms (Table I). Initial values for all variables assessed were on average above age-matched norms (Table I). Initial BMD values were independent of body mass, of leg extensor power and dietary intakes of energy, calcium, protein, fibre and phosphorus.

The calcium intakes from the initial food frequency questionnaire correlated significantly with the 3 day weighed record (r=0.61, P<0.001), with a small mean difference of 45±326 mg. The large SD was due to a few women on vegetarian diets who score too low on the restricted list of the food frequency questionnaire. One of these women had an intake of 2419 mg/day. No major discrepancies were detected by the diet history. Baseline calcium intake was independent of body mass, but significantly correlated with energy intake (r=0.64, P<0.001, n=45).

Energy intake was reduced according to the initial and 4 month weighed analyses (Table I), but there was a large variation in compliance with the diet. Reductions in calcium and energy intake were significantly correlated (r=0.38, P<0.02), but absolute calcium intake was no longer related to energy intake during dietary restriction. Calcium intake fell slightly, but significantly, mainly due to four subjects with the highest initial intakes (r=−0.79, P<0.001, n=42), but a few with low intakes managed an increase (Fig. 1). Despite the decrease in the range of calcium intakes, the initial and 4 month values remained significantly correlated for the group (r=0.54, P<0.001). There were also reductions in intakes of vitamin D, phosphorus and absolute (g) intakes of protein, carbohydrate and fat. Dietary fibre intake did not change significantly. Although the percentage of energy intake as protein increased (P<0.01), the relative contributions of carbohydrate and fat did not change, so dietary restriction appears to have been achieved by reducing portion size rather than changing to a lower fat, higher carbohydrate diet.

Leg extensor power decreased slightly from 216±41 W to 208±39 W (P<0.01). The change was not related to changes in BMD or body mass.

In the first 3 months all the women lost body mass by a mean value of 3.3±2.2 kg (range -9.5 to -9.35 kg), but in the second 3 months only 18 women lost more body mass and of those only six lost more than 1 kg; three women regained more than 2 kg. The 3 month loss and the overall loss were significant, but weakly, related to the reported reduction in energy intake (r=0.36 and r=0.34, respectively, P<0.05), the loss was smaller than expected for the reported energy intake deficit. Overall, heavier subjects tended to lose more body mass (r=−0.41, P<0.01, n=45).

There was no mean change in TBBMD after 3 months of dietary restriction and none of the subjects had fallen to levels which would warrant withdrawal from the study (i.e. 1SD below the mean for young women, Lunar population norms, Lunar Corp. DPX-L technical manual, documentation version 9/92). By 6 months, slight, but significant, decreases were found in TBBMD (0.7%) and in BMD at the lumbar spine 0.5% (Table 2). There were no significant changes in the femur. Total bone mineral content changed in the same direction as TBBMD and by a similar percentage, 0.8% (0.02±0.01) kg, but not quite significantly (P=0.066) in this more variable measurement. For those who had lost more than 5% of their body mass at 6 months (n=23) the loss of BMD was about twice that found for the whole group. The loss was highly significant in the total body (−0.015±0.003 g/cm², P<0.001) and all component regions, except the head and legs, and also at the spine (−0.013±0.004 g/cm², P<0.001), but not the femur.

The losses in TBBMD and BMD at the lumbar spine for the whole group were significantly associated with loss of body mass (P<0.05 for both)
Table 2. Changes in body mass, BMD and bone mineral content (BMC) evaluated using Student's paired t-test. Values are shown as mean (SEM), n=45.

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>6 months</th>
<th>Change</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>67.3 (1.01)</td>
<td>64.0 (0.93)</td>
<td>-3.3 (0.46)</td>
<td>0.001</td>
</tr>
<tr>
<td>BMD (g/cm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine L1-L4*</td>
<td>1.217 (0.018)</td>
<td>1.211 (0.018)</td>
<td>-0.006 (0.003)</td>
<td>0.051</td>
</tr>
<tr>
<td>Total body</td>
<td>1.187 (0.009)</td>
<td>1.179 (0.008)</td>
<td>-0.008 (0.002)</td>
<td>0.0016</td>
</tr>
<tr>
<td>Total body BMC (kg)</td>
<td>2.48 (0.03)</td>
<td>2.46 (0.03)</td>
<td>-0.02 (0.01)</td>
<td>0.066</td>
</tr>
</tbody>
</table>

* n=44.

Table 3. Pearson product correlation coefficients (r) for changes in BMD. r>0.30, P<0.05; r>0.40, P<0.01; n=41.

<table>
<thead>
<tr>
<th></th>
<th>Total body</th>
<th>Spine (L1-L4)</th>
<th>Femoral neck</th>
<th>Trochanter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial calcium intake</td>
<td>0.43</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Reduced calcium intake</td>
<td>0.46</td>
<td>0.30</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Change in calcium intake</td>
<td>NS</td>
<td>0.37</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Change in body mass</td>
<td>0.34</td>
<td>0.28</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

(Table 3) and also with the reduced absolute calcium intake (assessed using the 3 day weighed intake) during dietary restriction (P<0.01 and P<0.05, respectively). In stepwise multiple regression analysis, with the change in TBBMD as the dependent variable, the reduced absolute calcium intake, initial TBBMD and change in body mass were all independent predictors of the change. The regression equation (n=42) is

\[ R^2 (\text{explained variance}) = [0.079 + 3.18 \times 10^{-5} \text{ calcium intake (mg)}] + 0.092 \text{ initial TBBMD (g/cm}^2) + 1.617 \times 10^{-3} \text{ change in body mass (kg)} \]

Total 0.38

For BMD at the lumbar spine, in multiple regression, only the reduced absolute calcium intake remained as a significant predictor of loss of BMD. It was surprising that absolute levels rather than the reduction in calcium intake were significantly related to the losses in BMD. These relations were confounded because the changes in calcium intake were negatively related to the baseline intake so that many women reduced their intake whilst remaining above 800 mg/day. The most extreme example of this was the vegetarian with the exceptionally high calcium intake (2419 mg/day), who halved her intake. When she was omitted from the analysis the change in dietary calcium became significantly related to the change in BMD at the spine (r=0.37, P<0.02, n=40) (Fig. 2); however, her removal made little difference for TBBMD. Changes in the femur were not related to changes in body mass or calcium intake.

In order to compare our data with the findings from two other studies of body mass loss and BMD, a subgroup of 25 women with calcium intakes of at least 800 mg/day during dietary restriction was selected (Fig. 3). This subgroup did not change significantly in TBBMD over the 6 months of the study, but the relation between change in body mass and change in TBBMD was highly significant. The residual group of 17 women with calcium intakes below 800 mg/day during dietary restriction showed highly significant decreases of over 1% in TBBMD (−0.016 g/cm² ± 0.004 SEM, P<0.001) and BMD at the lumbar spine (−0.014 ± 0.005, P<0.02).

**DISCUSSION**

This dietary intervention was modest, but nevertheless there was an associated significant fall in BMD which was apparent in two independent
Bone mineral density and weight loss

compliance resulted in variable changes in body mass, it was possible to consider the relations between these changes and those found in BMD. The significant relationship between change in body mass and change in BMD was consistent with the theory that the most important influence on bone mass is the load it is required to bear [29, 30] and suggested that a modest decrease in daily load could initiate changes in bone remodelling to produce a detectable fall in BMD. However, the relation for the femur was not significant, despite its weight-bearing role. This would have to be explained by the greater unreliability of BMD measurement at this site. The decrease in leg extensor power suggested that activity levels may have fallen a little, which would contribute to a decrease in bone loading. These longitudinal findings are consistent with cross-sectional studies in premenopausal women, which with the exception of that of Stevenson et al. [10], have found a significant association between body mass and BMD [9, 11–13], with body mass explaining 10–15% of the variation.

The findings are also consistent with two other studies of more uniform dietary restriction in older women, which were shorter in duration, and in which dietary calcium was maintained at 800 mg/day (Fig. 3). Decreases of 1.9% in TBBMD and of 1.6% in BMD at the spine were found in association with a 12% loss of body mass in postmenopausal women on a diet of 4200 kJ/day for 12 weeks [15]. The diet was similar to that reported in the present study, but compliance was evidently better since the loss of body mass was larger. In the second study, a significant 2.5% loss of TBBMD accompanied a 17% loss of body mass induced by severe dietary restriction for 10 weeks [16]; the diet was uniform, providing 1701 kJ daily. BMD was not measured until 6 months had elapsed in the present study; it is possible that the other authors might have found larger decreases in BMD if they had been able to maintain their groups at the reduced body mass for this length of time. Compton et al. [16] attributed the loss of BMD to a fall in oestrogen derived from fat tissue [31] in this mainly postmenopausal group [14], but the oestrogen levels were not reported. In the present study the women were eumenorrheic and so were presumed to have normal premenopausal levels of circulating oestrogen with no need for oestrogen derived from body fat. The concordance seen in Fig. 3 suggests that the primary mechanism in all three studies may be the loss of body mass.

The observed loss of body mass in the present study is considerably less than would be expected if the energy deficit reported at 4 months had been maintained throughout the 6 months. Severe dietary restriction can lead to a more efficient metabolism, but this is not sufficient to explain the observed deficit [32]. The shortfall is probably accounted for by bias in the choice of foods during the 3 day weighed intake; it is well known that dietary observation induces behavioural change [33].

The results make it clear that calcium intake was important for the maintenance of BMD during dietary restriction and suggest that bone is more sensitive to a reduction in body mass in the presence of lower dietary calcium. This was surprising since only 10 women fell below the recommended nutritional intake of 700 mg/day for calcium intake [34]. They may have overestimated calcium intake with a more judicious choice of foods during their 3 day weighed food recording despite the underreporting of energy intake. A threshold for calcium intake at about 800 mg/day has been reported [35, 36], but the subgroup reporting intakes at or above that level showed a significant relation between change in calcium intake and change in TBBMD. Calcium absorption is variable and can be perturbed by changes in other dietary components, such as fibre [18, 19]; however, in the present study dietary fibre intake was modest to begin with and there was no increase. Some women may have experienced a negative calcium balance sufficient to decrease serum calcium and increase the release of parathyroid hormone. This would stimulate increased reabsorption of calcium by the kidney and better absorption of dietary calcium from the gut, but would also increase bone turnover and osteoclastic activity. This results in net bone resorption and a fall in BMD [37].

The loss in BMD observed in this study of dietary restriction was modest and occurred in women with high absolute BMD. A similar loss could be a threat among women with much lower BMD.

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REFERENCES


