The effect of exercise on bone mineral density in premenopausal female athletes compared with non-athletes

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Abstract

Objectives
The objective of this preliminary study was to determine the effect of exercise, diet, menstrual status and anthropometry on the bone mineral density (BMD) of the spine, hip and forearm of young Caucasian female athletes aged 20 - 30 years.

Design
Nine female athletes and a control group (N = 9) were recruited within the same range for age and body mass index (BMI). Weight, height and skinfolds were measured. Dietary intakes were assessed using a validated food frequency questionnaire. An activity and a medical questionnaire were also completed. BMD was measured using dual energy X-ray absorptiometry (DEXA) at the lumbar spine, left hip and forearm.

Results
No significant difference between reported nutrient intakes of athletes and controls was found. Significant negative correlations were found between spine BMD of the whole group (N = 18) and total calcium intake, as well as between forearm BMD and luteal phase, menstrual cycle and number of active exercise hours per week. Athletes had a significantly lower forearm BMD, lower percentage body fat and longer active exercise time per week. Women with a history of amenorrhea (N = 3) had a lower average BMD and exercised significantly more than the eumenorrheic women.

Conclusion
It is suggested that active weekly exercise, menstrual status and percentage body fat may all have a direct or indirect effect on the forearm BMD of white female athletes. Exercising premenopausal women are advised to lower lifestyle risk factors that may lead to a low BMD at a young age, to maintain a percentage body fat of > 12 - 14%, and if amenorrhea is present, to undergo medical examination to identify the cause. However, because of the limited number of subjects in the study, no definite recommendations can be made.


It is well documented that a low peak bone mass in premenopausal women is a major determinant for the risk of osteoporotic fracture later in life.1 Entering the menopause with a skeletal mass less than average also increases the risk of future osteoporosis.1-3

To achieve one's genetic potential of bone synthesis during growth requires a healthy childhood, moderate weight-bearing activity to ensure adequate skeletal development, and sound nutrition to supply the ingredients for optimal bone mineralisation.3 Since peak bone mass is achieved between the ages of 25 and 30 years, extra care should be taken by teenagers and young adults to avoid or reduce the possible risk factors for developing low bone mineral density (BMD).4

Many factors affect BMD and risk of osteoporosis.5 Young elite female athletes who exercise excessively and start training at a young age may have a low percentage of body fat. This may lead to a lack of oestrogen exposure, as well as influencing hormones such as...
progestosterone, increasing levels of cortisol, and compromising nutritional status.3.4,6 Owing to these risk factors, they may not be able to reach their optimal peak bone mass and have a greater risk of developing osteoporosis and fractures at a younger age than non-athletes.

It is now recognised that a substantial portion of female athletes experience menstrual dysfunction associated with increased levels of exercise training, which may seriously affect their bone metabolism.7 Low oestrogen levels are associated with an increase in bone resorption and thus an increase in bone loss. In amenorrhoic athletes with reduced circulating oestradiol and progesterone, reduced bone density and increased musculoskeletal injury rates manifest.7,8 Irreversible loss of bone mineral content may occur after 3 years of amenorrhoea.9 Therefore, athletes with severe hypo-oestrogenism are at high risk for the development of osteoporosis at a young age (premenopausal). Possible aetiological factors for menstrual cycle interval disturbances (MDs) in athletes include body size,10 prior menstrual irregularity,11,12 training distance13 and late onset of menarche.11 However, Watkin and co-workers14 did not find any relationship between MDs and high weekly training distance, low body mass, or low body mass index (BMI). Therefore, the occurrence of secondary amenorrhoea in young athletes warrants investigation regarding the aetiology of the condition and further therapeutic intervention.13

There is a definite relationship between bone health, eating disorders and amenorrhoea.15 Pressure from coaches and team mates to maintain a slim figure may lead to female athletes developing eating disorders, of which anorexia nervosa is the most prominent. A low body weight and body fat percentage are both associated with a lower BMD and amenorrhoea.9,16,17 A low kilojoule intake in relation to high energy expenditure during training in female runners has been reported by several investigators.18,19 It has also been reported that amenorrhoeic runners have a significantly lower daily kilojoule intake compared with that of eumenorrhoeic runners.14,19 However, some studies have found no difference in the nutritional intakes of amenorrhoeic and eumenorrhoeic athletes.18,20

A low energy intake may also be associated with a decreased calcium intake.21 Much controversy surrounds calcium intake and BMD, but various epidemiological studies have shown an association between lifelong high calcium intakes and higher bone mass during growth, fewer fractures during adolescence, and better BMD.16,21

Strenuous exercise itself may also contribute to a lower bone density and increase the risk of stress fractures. It is hypothesised that strenuous exercise accelerates bone remodelling.22 Since osteoblastic resorption always precedes formation in the remodelling process, there is a lag time in which the bone has a lowered bone density.22

It is also important to consider family history of osteoporosis since the genetic contribution to variability in bone mass has been estimated to be as high as 80%.23

Despite these known facts about the role of exercise and diet in BMD, very little is known about the magnitude of their role in South African female athletes. The aim of this cross-sectional, analytical study was to determine the influence of activity, nutrient intake, menstrual status, weight and height on BMD in young female athletes aged 20 - 30 years.

**Methods**

**Subjects**

Nine white female athletes between the ages of 20 and 29 years were recruited. Athletes from Potchefstroom and surrounding areas were located through athletic clubs, and contacted by telephone. Exclusion criteria were age ≥ 30 years, pregnancy and lactation, endocrine abnormalities and bisphosphonate or vitamin D/fluoride therapy. Two of the athletes were cyclists, 4 were marathon runners and 3 were long distance (10 - 15 km) runners. All the athletes completed baseline measurements. The control group included female non-athletes within the same range for BMI and age (Table I). Subjects gave written consent to participate in the study and the study was approved by the Ethics Committee of the Potchefstroom University.

<table>
<thead>
<tr>
<th>Table I. Characteristics of athletes and non-athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>Height (m)</td>
</tr>
<tr>
<td>Body mass index (kg.m⁻²)</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Spine BMD (g.cm⁻²)</td>
</tr>
<tr>
<td>Hip BMD (g.cm⁻²)</td>
</tr>
<tr>
<td>Forearm BMD (g.cm⁻²)</td>
</tr>
<tr>
<td>Total BMD score (g.cm⁻²)</td>
</tr>
<tr>
<td>T-score for spine BMD</td>
</tr>
<tr>
<td>T-score for hip BMD</td>
</tr>
</tbody>
</table>

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## Anthropometry

Height was measured using a stadiometer (Invicta Metrimeasure IP 1465, Educational Aids Division, Oadby, Leicester, England) to the nearest 0.1 cm. Weight was measured using an electronic scale to the nearest 0.1 kg and skinfold measurements were taken to the nearest 1 mm using a caliper (Slimguide, Creative Health Products). Skinfolds were measured for athletes and non-athletes as recommended by Heyward and Stolarczyk.24 The skinfolds measured for athletes were the triceps, supra-iliac and thigh, and for non-athletes skinfolds were measured for the triceps, supra-iliac, abdomen and thigh. The percentage body fat was calculated from these skinfold measurements by using the formula of Jackson et al.25 BMI was calculated from height and weight in kg/m².

### Dietary analysis

A quantitative food frequency questionnaire, validated by Vorster et al.26 in four South African ethnic groups, was administered during personal interviews and analysed using the Dietary Manager computer software program. The use of dietary supplements was also recorded. Five athletes took calcium supplements and 2 took vitamin D supplements. None of the control subjects took supplements.

### Activity questionnaire

A retrospective activity questionnaire developed by Grimby et al.27 measuring the intensity of occupational and non-occupational activities was completed. The hours of exercise per week were also documented.

### Menstrual cycle

The date of menarche, regularity of menstrual cycle, period of cycle, days of mense, luteal phase and use of oral contraceptives and the reason for using these were noted.

### Medical history

The goal of the questionnaire was to collect information on medication and diseases that might affect metabolism. Questions on family history of osteoporosis, the presence of milk allergy, smoking habits and eating disorders were included.

### Bone mineral density

BMD and T-scores were measured using dual energy X-ray absorptiometry (DEXA) (Hologic QDR 4500, Scientific Pharmaceuticals, Jasco), with a coefficient of variance (CV) of 1.0%. The three areas measured by a qualified nursing sister were the lumbar spine (L2 - L4), left hip (total (L)), forearm (radius and ulna (L)). A physician, who is also an osteoporosis specialist (GJAB), interpreted the results. Statistical analysis

The Statistica28 package was used to analyse the data. The means and standard deviations (SD) of all measured variables for the total group of athletes and non-athletes were analysed using Student’s t-test. Pearson correlations between BMD and measured variables were determined.

### Results

Five athletes and 6 non-athletes took oral contraceptives. Four athletes took contraceptives to prevent pregnancy and 1 to regulate the menstrual cycle. Three non-athletes took contraceptives because of skin problems, 1 for contraceptive purposes and 2 to regulate the menstrual cycle. Two athletes and 1 non-athlete had a history of amenorrhoea of longer than 6 months. The reasons given for this were training too hard, being too thin, and having a history of bulimia nervosa. The mean age of menarche for athletes was 14.7 years, and for non-athletes 13.3 years. Only 1 athlete and 2 non-athletes smoked moderately (± 10 cigarettes/day). One non-athlete had a history of bulimia nervosa, 1 non-athlete had a milk allergy, and 1 athlete and 1 non-athlete had a family history of osteoporosis. As seen in Table I, there was no significant difference between the mean BMD of the lumbar spine and hip in athletes and non-athletes. The difference in BMD of the forearm between the groups was, however, statistically significant (P = 0.03), which confirms the negative correlation observed between forearm BMD and active exercise hours per week (Table II). When comparing the T-scores of all measured sites in both groups with the World Health Organisation (WHO)29 criteria for osteoporosis, the mean values of all measured sites fell in the category < -1.0 SD below the mean, which indicates normal bone mass. The exceptions were 1 athlete who was osteopenic at the lumbar spine and forearm site, as well as 1 non-athlete (with a history of bulimia nervosa) who was osteopenic at the lumbar spine site.

### Table I

<table>
<thead>
<tr>
<th>T-score for forearm BMD</th>
<th>-0.410</th>
<th>0.613</th>
<th>0.001</th>
<th>0.546</th>
<th>0.154</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mense (days)</td>
<td>4</td>
<td>1.5</td>
<td>4</td>
<td>1.6</td>
<td>0.657</td>
</tr>
<tr>
<td>Menstrual cycle (days)</td>
<td>30</td>
<td>3</td>
<td>26</td>
<td>10</td>
<td>0.314</td>
</tr>
<tr>
<td>Luteal phase (days)</td>
<td>25</td>
<td>3</td>
<td>22</td>
<td>9</td>
<td>0.293</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>8+</td>
<td>4.9</td>
<td>14.6+</td>
<td>3.5</td>
<td>0.004</td>
</tr>
<tr>
<td>Active exercise (h.wk⁻¹)</td>
<td>8+</td>
<td>3</td>
<td>4+</td>
<td>2</td>
<td>0.011</td>
</tr>
</tbody>
</table>

* Student t-test.
+ Significant difference between athletes and non-athletes P < 0.05.
Ø The sum of hip BMD + spine BMD + forearm BMD, ‡ 3.
Luteal phase = menstrual cycle in days - mense in days.
BMD = bone mineral density.
Athletes also had a significantly lower percentage of body fat (8% v. 14.6%, P = 0.004) and longer active exercise time per week than non-athletes (P = 0.011).

**Table II. Significant Pearson correlations between bone mineral density and other variables in the total group (N = 18)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lumbar spine BMD</th>
<th>Hip BMD</th>
<th>Forearm BMD</th>
<th>Mean BMD score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dietary calcium (mg)</td>
<td>-0.60</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Menstrual cycle (days)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Luteal phase (days)</td>
<td>NS</td>
<td>NS</td>
<td>-0.48</td>
<td>NS</td>
</tr>
<tr>
<td>Active exercise (h.wk⁻¹)</td>
<td>NS</td>
<td>NS</td>
<td>-0.52</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS = not significant.

There were no significant differences between the reported nutrient intakes of athletes and non-athletes (Table III). The energy, total protein and total calcium intakes of the athletes were slightly higher than those of the non-athletes, but the remaining dietary vitamin and mineral intakes were the same. When intakes of both groups were compared with the recommended daily allowances (RDA)30 or the latest dietary reference intakes (DRI)31 for women, total protein intake was higher (athletes 73 g, non-athletes 66 g), grams of protein per kilogram body weight consumed was higher (both groups ± 1.1 g/kg), total calcium intake was somewhat lower than the recommended intake31 (athletes 1 035 mg, non-athletes 879 mg) but not less than 67%, vitamin D intakes were lower, and phosphorus intake was satisfactory. Because of adequate sunlight exposure in South Africa, vitamin D status should not be a problem. The RDA30 for energy for women aged 19 - 50 years is 9 240 kJ per day. Total daily kilojoule intake of athletes (8 264 ± 2 032 kJ) was only 89% of the RDA, but this was higher than the reported energy intake of other South African marathon runners.14 Non-athletes reported a lower total daily kilojoule intake (7 091 ± 1 932 kJ) than athletes and only consumed 76% of the RDA. Owing to the low energy intakes reported by athletes and non-athletes, the ratio of energy intake (EI) to basal metabolic rate (BMR) was estimated to establish whether energy intake was underreported. Bingham and Nelson32 suggest that EI/BMR ratios below 1.2 for measured BMR are likely to reflect underreporting of energy intake. BMR was calculated using the Schofield equation.33 The calculated EI/BMR ratio for athletes was 1.42 and 1.27 for non-athletes, indicating that the respondents probably did not underreport food intake.

**Table III. Nutrient intakes of athletes and non-athletes compared with the recommended daily allowances30 and dietary reference intakes31**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Athletes (N = 9)</th>
<th>Non-athletes (N = 9)</th>
<th>RDA/DRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Total energy (kJ)</td>
<td>8 264</td>
<td>2 032</td>
<td>7 091</td>
</tr>
<tr>
<td>Total protein (g)</td>
<td>73</td>
<td>22</td>
<td>66</td>
</tr>
<tr>
<td>Fibre (g)</td>
<td>25.9</td>
<td>8.5</td>
<td>23.5</td>
</tr>
<tr>
<td>Total calcium* (mg)</td>
<td>1 035</td>
<td>311</td>
<td>879</td>
</tr>
<tr>
<td>Magnesium (mg)</td>
<td>323</td>
<td>84</td>
<td>328</td>
</tr>
<tr>
<td>Phosphorus (mg)</td>
<td>1 333</td>
<td>332</td>
<td>1 147</td>
</tr>
<tr>
<td>Vitamin D (µg)</td>
<td>2.1</td>
<td>1.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Calcium:protein (mg:g)</td>
<td>13.3</td>
<td>7.2</td>
<td>13.1</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>2 091</td>
<td>964</td>
<td>1 974</td>
</tr>
<tr>
<td>Caffeine (mg)</td>
<td>359</td>
<td>134</td>
<td>364</td>
</tr>
</tbody>
</table>

* Dietary as well as supplemental calcium.

RDA = recommended daily allowances; DRI = dietary reference intakes; SD = standard deviation.

The participating women were also divided into two groups according to history of amenorrhoea. A significant difference (P = 0.03) was found in the active exercise hours per week between women with a history of amenorrhoea and those with no history (Table IV). Women with a history of amenorrhoea (N = 3) tended to have a lower average BMD (not significant) and a significantly lower protein intake (0.8 g/kg v. 1.2 g/kg. P = 0.01). However, no differences were found between the two groups with regard to body weight, total daily EI, BMI and percentage body fat.

**Table IV. Effect of amenorrhoea on measured variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>History of amenorrhoea (N=3)</th>
<th>No history of amenorrhoea (N=15)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Total energy (kJ)</td>
<td>6 372</td>
<td>2 500</td>
<td>7 938</td>
</tr>
<tr>
<td>Total protein (g)</td>
<td>50.5*</td>
<td>7.4</td>
<td>72.9*</td>
</tr>
<tr>
<td>Fibre (g)</td>
<td>28.3</td>
<td>10.4</td>
<td>24.0</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>947</td>
<td>285</td>
<td>870</td>
</tr>
<tr>
<td>Vitamin D (µg)</td>
<td>0.7*</td>
<td>0.3</td>
<td>2.4*</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>58.8</td>
<td>5.4</td>
<td>59.1</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.69</td>
<td>0.94</td>
<td>1.68</td>
</tr>
<tr>
<td>Body mass index (kg.m⁻²)</td>
<td>20.5</td>
<td>1.6</td>
<td>20.8</td>
</tr>
</tbody>
</table>

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A significant negative correlation was found between spine BMD of the total group and dietary calcium intake (-0.60) (Table II, Fig. 1A). Forearm BMD of the total group also showed significant negative correlations with length of menstrual cycle (-0.48), luteal phase (-0.52) and active exercise hours per week (-0.66, Fig. 1B).

**Discussion**

Two subjects had osteopenic bone and 16 had normal BMDs when comparing the T-scores with the WHO29 recommendations. Forearm BMD is usually used as an indicator of peripheral bone mass and therefore accounts for long bone (leg) mass.34 Therefore, athletes could have a higher risk of stress fracture in their legs than non-athletes, indicated by their low forearm BMD. Optimal levels of calcium in the diet are thought to be necessary for maximising bone mass in adolescents and young adults, as well as for slowing or preventing bone mass later in life.35,36 Several studies37,38 have shown that there is a positive relationship between dietary calcium intake and bone measurements. However, other studies,39,40 including this study, have found no significant relationship between calcium intake and BMD, or a significant negative correlation between these variables.39,40 Kirchner et al.40 found a moderate negative correlation between current calcium intake and lumbar spine BMD in gymnasts (r = -0.40, P < 0.05). In addition, a significant correlation (P < 0.05) was noted between gymnastics participation and calcium intake, namely as calcium intake increased, lumbar spine BMD decreased in gymnasts and increased in controls. Mazess and Barden39 indicated with multiple regression analysis incorporating age, height, weight, calcium and BMD that calcium intake is not a significant predictor of BMD at any site in premenopausal women. This interaction between dietary calcium and BMD in athletes is not easily explained, but it is important because it could influence dietary advice given to athletes.

This study showed a mean EI in both groups below the RDA. The possibility of subjects underreporting their daily energy intakes was ruled out by measuring the mean EI/BMR ratio in both groups. The recommended energy intake for female athletes with an average weight of 60 kg and between the ages of 18 and 30 years is 10 359 - 12 085 kJ per day, with an activity factor of 1.9 (moderate) and 2.1 (heavy).41 According to these recommendations it is clear that the athletes in this study had insufficient energy intakes. Watkin and co-workers14 also found that women runners had a lower energy intake than would be expected when considering their energy expenditure. This constant low energy intake and high energy output/need (considering active exercise hours per week) may result in low adipose tissue stores (as reflected by percentage body fat in both groups), which may lead to lower oestrogen levels and may result in amenorrhoea.42 Both athletes and non-athletes had body fat levels below recommended levels.9 Low oestrogen levels are associated with increased bone resorption and therefore an increase in bone loss,8 which might explain the low forearm BMD found in both groups. In this study, amenorrhoeic women had similar nutrient intakes compared with eumenorrhoeic athletes, with the exception of a lower protein intake. Drinkwater et al.13 found that amenorrhoeic runners have significantly lower daily energy intakes than eumenorrhoeic athletes; however, Schwartz et al.20 and Watkin et al.14 found no differences in the nutrient intakes of amenorrhoeic and eumenorrhoeic athletes. The data of this study seem to support other studies10,43 which found an association between a vegetarian diet or a low intake of red meat and the onset of MD. Heavy exercise can also induce amenorrhoea.44 Since the women with a history of amenorrhoea were more active (Table IV) than the women with no history, it is possible that exercise-induced amenorrhoea was present. However, it is difficult to draw any conclusions from these results because of the small size of the study group.

**Conclusions**

This study showed that active exercise hours per week, luteal phase, menstrual dysfunction and percentage body fat all had a direct or indirect effect on forearm BMD in a group of white premenopausal women. When comparing athletes with non-athletes, it seems as if BMI or body mass may not be good predictors of BMD. Percentage body fat and active exercise hours per week should rather be used.

The design of this study with its small number of subjects does not allow for conclusions regarding the independent effect of exercise on menstrual cycle length and luteal phase. However, it is suspected that the number of active exercise hours per week may be responsible for the relationship between these two variables and forearm BMD.
No significant correlations were found between nutrient intakes and BMD, except for a negative correlation between dietary calcium intake and BMD.

The following recommendations can be made to female athletes: (i) female athletes aged 20-30 years should not have under 12% body fat - Opplinger and Cassady9 gave a general guideline that body fat for female athletes should be over 12-14%; (ii) exercising premenopausal women with a high risk for the development of osteoporosis may need to reduce the number of active exercise hours per week to less than 7.5 hours; and (iii) amenorrhoeic women aged 18-30 years should be examined medically to determine the cause of the menstrual dysfunction and should be treated accordingly. Owing to the small groups in this study and the many confounding variables, definite recommendations cannot be made and a larger study adjusting for these variables is recommended.

References


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