Different training patterns and bone mineral density of the femoral shaft in elite, female athletes

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Abstract

The effects of sporting activity and of menstrual status on the bone mineral content of the femoral mid-shaft were investigated. The cohort consisted of 67 elite, female athletes comprising 21 runners, 36 rowers, and 10 dancers. Twenty five of these athletes were amenorrhoeic, 27 eumenorrhoeic, and 15 were taking the oral contraceptive. The bone mineral content was also measured in 13 eumenorrhoeic, sedentary women. The mean (95% confidence interval) bone mineral content in the runners was 1.51 (1.47 to 1.55) g/cm², which was significantly higher than in the rowers, dancers, and sedentary controls whose values were 1.43 (1.40 to 1.47), 1.39 (1.33 to 1.45), and 1.40 (1.34 to 1.45) g/cm² respectively. There was no significant difference in the bone mineral content between the amenorrhoeic, eumenorrhoeic, and oral contraceptive taking athletes. These results may have implications for devising exercise strategies to reduce the possibility of fractures in later life.

Both human¹ and animal^{2,3} studies have shown that exercise can increase bone density, but there is still uncertainty about the type and the intensity of exercise that provides maximum anabolic stimulus to bone. Animal studies³ have suggested that a threshold effect occurs at quite low levels of stress loading with no further benefit at higher levels. In contrast, human studies have shown that intensive exercise—for example, in athletes, does produce an additional increase in bone density.¹ Studies in humans have also shown a direct relation between aerobic capacity (VO₂max) and bone mineral density.^{4,5} In female athletes, in whom intensive training leads to amenorrhoea, there is a paradoxical fall in bone mineral density.^{6,7} These studies have shown that although trabecular bone density is reduced, cortical bone in the upper limb remains unaffected.^{6,7}

We measured the bone mineral content in the right femoral mid-shaft, a site known to consist almost entirely of cortical bone, in a large group of elite female athletes comprising rowers, runners, and ballerinas. These results were compared with those for a eumenorrhoeic, sedentary control group, allowing us to explore the effects of three types of training. Aerobic capacity was measured and the effect of menstrual status was also investigated.

Subjects and methods

Sixty seven elite, female athletes agreed to participate in the study. This group included 36

national squad rowers, 21 endurance runners, who had either run internationally or were marathon runners with a personal best of under three hours, and 10 full time professional ballet dancers. Twenty five of these athletes were amenorrhoeic—that is, one or less periods in the previous six months, 27 eumenorrhoeic—that is, regular periods with a cycle length of less than 35 days, and 15 were taking the oral contraceptive. These were compared with a group of 13 eumenorrhoeic, sedentary women of similar age, who acted as a control group.

The aerobic capacity (VO₂max) was measured in each athlete. Continuous expired gas analysis was measured with the Jaeger EOS Sprint automated system and the heart rate determined with a Rigel cardiac monitor while the exercise was performed using a Tunturi EL 400 cycle ergometer. The protocol consisted of incremental workloads starting at a load of 50–80 W and progressing by 30 W steps until volitional exhaustion. The criteria for achieving VO₂max were (a) heart rate within five beats of the age related maximum heart rate (220–age of patient); or (b) an increase in load not accompanied by an increase in oxygen uptake (VO₂); or (c) a respiratory quotient greater than 1.15.

The bone mineral content of a 4 cm length of the mid-shaft of the right femur was measured with a Novo BMC-Lab 22a dual photon absorptiometer. This site consists almost entirely of cortical bone. The scanner incorporated a radiation source of gadolinium-153 (half life 280 days), which emits photons of about 44 keV and 100 keV. The coefficient of variation for these measurements was about 1.5% and the dose equivalent at the site of measurement was 0.1 mSv.⁸ The results (bone mineral content) were expressed in g/cm².

STATISTICAL METHODS

One way analysis of variance (ANOVA) was used to test whether bone mineral content and demographic variables such as age, height, and weight differed in the four groups (dancers, rowers, runners, and sedentary controls.) When the ANOVA was significant, indicating that there were differences between the groups, the Tukey procedure⁹ was used to determine where the individual differences lay. Confidence intervals for the means of individual groups were constructed using the degrees of freedom and mean square error from the ANOVA.

Linear models^{10,11} were used to assess which variables (age, height, weight, sporting group, and menstrual status), or combination of them, were most closely related to femoral shaft bone mineral content. The residuals from the

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Accepted for publication
28 August 1990

Demographic variables (mean with 95% confidence interval) in the four groups

	Sedentary controls (n=13)	Dancers (n=10)	Rowers (n=36)	Runners (n=21)	ANOVA*
Age (years)	28.4 (26.5 to 30.3)	22.8 (20.7 to 25.0)	24.7 (23.5 to 25.8)	26.0 (24.5 to 27.5)	$F_{3,76}=6.01$ $p<0.0011$
Weight (kg)	54.8 (51.3 to 59.3)	50.7 (46.7 to 54.7)	62.9 (60.8 to 65.0)	50.9 (48.1 to 53.7)	$F_{3,76}=20.36$ $p<0.0001$
Height (cm)	161 (157 to 164)	164 (160 to 168)	171 (169 to 173)	164 (161 to 166)	$F_{3,76}=14.94$ $p<0.0001$
VO ₂ max (ml/kg/min)	—	45.5 (41.9 to 49.1)	53.8 (51.9 to 55.7)	59.9 (57.4 to 64.4)	$F_{3,64}=21.98$ $p<0.0001$

*ANOVA=one way analysis of variance.

ANOVA and the linear models were tested for normality using the Shapiro Wilk's W test¹² and for equal variances in the groups using the Schweder test.¹³

Analysis of covariance¹⁴ was used to see if the relation between bone mineral content and VO₂max varied between the sporting groups.

Results

The table gives details of the demographic variables in the groups. The ANOVA showed that age, weight, and height varied significantly between the four groups. The Tukey procedure showed that the sedentary controls were significantly older (28.4 years) than the dancers (22.8) and the rowers (24.7) with the runners (26.0) in between. The rowers were both heavier (62.9 kg) and taller (171 cm) than the other three groups, who were similar for these two variables. VO₂max also varied significantly between the three sporting groups, being highest in the runners (59.9 ml/kg/min), who had higher values than the rowers (53.8) who, in turn, had higher values than the dancers (45.5).

Figure 1 gives the mean bone mineral content and 95% confidence intervals for the four groups. The ANOVA showed that bone mineral content varied significantly between the sporting groups ($p=0.0026$). The bone mineral content in the runners (1.51 g/cm²) was significantly higher than that in the rowers (1.43 g/cm²), dancers (1.39 g/cm²), and sedentary controls (1.40 g/cm²), whose levels were similar.

Figure 2 gives the mean bone mineral content and 95% confidence intervals in the three menstrual groups. In the amenorrhoeic and eumenorrhoeic athletes the mean was 1.45 g/cm² and in the oral contraceptive takers it was 1.46 g/cm². These results were not significantly different from those for the sedentary control group ($p=0.38$).

When the linear models were used only sporting group was related to bone mineral content (fig 1). Age, height, and weight were not related at all to bone mineral content ($p=0.68$, 0.46 , 0.73 respectively). Furthermore, although VO₂max varied between the sporting groups, being highest in the runners, it too was not related to bone mineral content. Analysis of covariance showed that this result applied both collectively and to each sporting group individually.

Discussion

Previous studies have shown that cortical bone mineral content in the upper limb is not reduced in amenorrhoeic athletes compared with their eumenorrhoeic counterparts.^{6,7,15} We also failed to show that cortical bone in the femoral mid-shaft is affected by low oestrogen status.

Nilsson *et al* showed that bone density in the femoral shaft is greater in athletes than non-athletes.¹ They were also able to show differ-

Figure 1 Mean (95% confidence interval) cortical bone mineral content (BMC) of the femoral shaft in the sporting groups.

Figure 2 Mean (95% confidence interval) cortical bone mineral content (BMC) of the femoral shaft in the menstrual groups. Sed=sedentary controls; Am=amenorrhoeic athletes; Eu=eumenorrhoeic athletes; OC=oral contraceptive takers.

ences between sports with mean values being higher in weight lifters than in runners who, in turn, had higher values than swimmers. We also showed major differences between sports with significantly higher levels in runners than in rowers, dancers, and non-athletes.

At least two studies have shown a positive correlation between bone mineral density and aerobic capacity (VO_2max). Chow showed a significant correlation between VO_2max and total body calcium, measured by neutron activation analysis, in 31 postmenopausal women.⁴ Pocock also showed a significant correlation in 38 premenopausal and 46 postmenopausal women between VO_2max and bone mineral density measured at the femoral neck and in the lumbar spine.⁵

These two studies differed from ours in several important respects. Both estimated VO_2max from the heart rate, whereas we measured oxygen uptake directly. We measured aerobic capacity in a younger age group with values at the top end of the range of VO_2max , whereas in the other studies the subjects were older and the mean VO_2max was much lower. Furthermore, the technique used for measuring bone density and the skeletal site at which the measurements were made differed in all three studies and therefore the results may not be directly comparable.

Dalsky *et al*, however, showed no relation between VO_2max , measured directly, and the bone density in the lumbar spine.¹⁶ Similarly, we were unable to show any relation between VO_2max and cortical bone mineral content even though the sporting group with the highest bone density (the runners) also had the highest aerobic capacity. We were also unable to show any relation between bone mineral content and VO_2max in any of the individual sporting groups. Aerobic training itself, therefore, may not act as a direct anabolic stimulus on bone.

The runners, who had the highest bone densities, do intense weightbearing exercise by running up to 70 miles/week. This produces considerable cyclical loading of the lower body. The dancers also do weightbearing exercise, but much of their work consists of slow movements involving coordination, balance, and flexibility with less than 10% involving jumping. The amount of cyclical loading is therefore much less. Rowing is chiefly a non-weightbearing sport. Although weight training of the legs forms part of the training, the degree of cyclical loading is much less than in running. These results suggest that intense cyclical loading may produce an anabolic effect on bone mineralisation in excess of moderate loading. Avian studies have shown,³ however, that only 36 cycles per day (occupying 72 seconds) were sufficient to saturate the anabolic stimulus and there may therefore be important differences between the human and avian models of cyclical loading.

It should be remembered, however, that this

is a cross sectional study. Therefore we cannot be certain that the starting bone density values were comparable in all four groups. Possibly, for example, the greater bone densities seen in the runners might have enabled them to train harder and thus have been a cause of their ability to do intense training rather than its effect. We consider this to be an intrinsically less likely explanation than the one offered.

Bone density increases at sites of maximum stress. For example, in tennis players, bone density levels in the playing arm are substantially higher than in the non-playing arm.^{17, 18} Runners have increased bone density in the calcaneus.¹⁹ We showed that runners may also have increased bone density values more proximally in the lower limb. If these differences are due to the anabolic effects of exercise and extend to sites of insufficiency fracture, our results may have implications for devising strategies intended to avert fractures later in life.

We are grateful to Dr J Reeve, Head of Bone Disease Research Group, for advice and support. RLW is supported by a grant from Glaxo Pharmaceuticals (UK) Ltd.

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