ORIGINAL ARTICLE

Low bone mineral density is two to three times more prevalent in non-athletic premenopausal women than in elite athletes: a comprehensive controlled study

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Objective: To compare bone mineral density (BMD), investigate factors associated with BMD, and examine the prevalence of low BMD in athletes and non-athletic controls.
Methods: The study included a questionnaire (part I), measurement of BMD (part II), and a clinical interview (part III). All Norwegian female athletes on national teams (n = 938) and an aged matched random sample of non-athletic controls (n = 900) were invited to participate. The questionnaire was completed by 88% of athletes and 70% of controls. A random sample of these athletes (n = 300) and controls (n = 300) was invited to participate in parts II and III. All parts were completed by 186 athletes (62%) and 145 controls (48%).
Results: Mean (standard deviation) total body (TB) BMD was higher ($p<0.001$) in athletes (1.21 (0.09) g/cm^2) than in controls (1.18 (0.08) g/cm^2), and higher ($p<0.001$) in high impact (HI) sports athletes than in medium impact (MI) and low impact (LI) sports athletes. In athletes, body weight and impact loading sports were positively associated, and percent body fat and eating disorders were negatively associated with TB BMD. Body weight and weight bearing activities were positively associated and menstrual dysfunction was negatively associated with TB BMD in controls. A higher percentage of controls (28.3%) than athletes (10.7%) had low BMD ($p<0.001$).
Conclusion: Female elite athletes have 3–20% higher BMD than non-athletic controls and HI sports athletes have 3–22% higher BMD compared with MI and LI sports athletes. Low BMD is two to three times more common in non-athletic premenopausal women than in elite athletes.

In recent years, the use of exercise to maintain bone health throughout life and ultimately prevent osteoporosis related fractures has received substantial research attention.[1 2] Immobilisation and skeletal unloading produce rapid bone loss, while weight bearing exercise has been shown to reduce bone loss and increase bone mass.[3] Cross sectional studies have shown that athletes, especially those undertaking strength training and/or high impact activities, have ~10% greater bone mineral density (BMD) than non-athletes.[4–7] Despite such findings, a few studies have shown that osteopenia and/or osteoporosis occur in some female athletes, especially those with disordered eating and/or menstrual dysfunction (MD).[8–13] However, to our knowledge, the BMD of such athletes is largely unknown, and no studies have compared the prevalence of low BMD in elite athletes representing all kinds of sports with non-athletic controls in the same age range. Therefore, the aims of this study were threefold: (i) to assess the differential BMD of athletes representing different sports and non-athletic controls, (ii) to investigate the factors associated with BMD, and (iii) to investigate the prevalence of low BMD in the same population.

METHODS

Participants

The total population of female elite athletes in Norway aged 13–39 years (n = 938) and non-athletic controls in the same age group (n = 900) was invited to participate. Permission to undertake the study was provided by the Norwegian Olympic Committee and the Norwegian Confederation of Sports, the Data Inspectorate, and the Regional Committee for Medical Research Ethics.

We defined an elite athlete as one who qualified for the national team at the junior or senior level, or who was a member of a recruiting squad for that team. The athletes represented 66 different sports/events and had to be 13–39 years old.[14] A bureau of statistics picked a randomly selected sample of controls (n = 900) from the total population of female citizens in Norway aged 13–39 years. Every county was represented and an approximate identical percentual age and geographical distribution in relation to the total population was ensured. None of the controls competed in sports for a national team and were thus classified as non-athletic controls.

Assessment procedures

Part I: screening

A questionnaire including a battery of assessment questions was sent to each of the 938 eligible athletes and 900 eligible controls. The response rates of the athletes and controls were 88.3% and 70.2%, respectively.[14]

In this study, a subject was determined to have MD if any of the following symptoms were reported: present primary amenorrhea, secondary amenorrhea, oligomenorrhea and short luteal phase, or a lifetime prevalence of primary or secondary amenorrhea.

The amount of physical activity among the controls was defined as the total hours of physical activity per week.[14] For

Abbreviations: BMD, bone mineral density; DSM-IV, Diagnostic and Statistical Manual of Mental Disorders; DXA, dual energy x ray absorptiometry; ED, eating disorder; EDE, Eating Disorder Examination; HI, high impact; LBM, lean body mass; LI, low impact; MD, menstrual dysfunction; MI, medium impact; NWBA, non-weight bearing activities; SD, standard deviation; TB, total body; WBA, weight bearing activities part II of this study, the physical activity data were summed in a manner reflecting the principles of mechanical loading on bone mass,[15] in that total sums of all weight bearing activities (WBA) (walking, ball games, dancing, aerobics, track and field, jogging, cross-country skiing, alpine skiing, martial arts, gymnastics, strength training, and racket sports) and non-weight bearing activities (NWBA) (swimming, bicycling, and the category ''other activities'') were calculated.

Selection for parts II and III

A stratified random sample of athletes (n = 300) and controls (n = 300), based on data from part I, was selected and invited to participate in parts II and III of the study. This sample was stratified based on age group (13–19, 20–29, and 30–39 years) and ''risk profile'' for the female athlete triad (the combination of disordered eating, menstrual dysfunction, and osteoporosis).[14] In total, 186 athletes (62%) and 145 controls (48%) participated in all three parts of the study.

Part II: assessment of BMD

BMD was measured with dual energy *x* ray absorptiometry (DXA) (Prodigy, GE Lunar, Chalfont St Giles, UK). The measurement areas were total body (TB), lumbar spine (L_2–L_4), femur neck, femur Ward's, femur trochanter, femur shaft, and total femur. All scanning and analyses were conducted by the same operator, and all measurement results were double checked for possible mistakes with regard to the analysis. Furthermore, a test of reliability was performed (n = 10). The coefficient of variance varied from 0.57% to 1.08% depending on the measurement sites.

Classification of groups based on mechanical loading

After the randomised selection of athletes was conducted, 46 different sports/events were represented in parts II and III of the study. For part of the analysis, the athletes were divided into three groups based on the degree of mechanical loading in their sport: low impact (LI), medium impact (MI), and high impact (HI) sports (table 1). The classification of athletes was based on a method developed by Groothausen and Siemer [16] and was done prior to data analysis.

Part III: clinical interview

In part III we included the Eating Disorder Examination (EDE)[17] to determine whether subjects met the criteria for subclinical or clinical eating disorders (EDs). Participants meeting the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria[18] for anorexia nervosa, bulimia nervosa, or EDs not otherwise specified, were categorised as subjects with EDs.

Statistical analysis and calculation of data

All analyses were performed using SPSS software, version 11.0 (SPSS, Evanston, IL). Results are expressed as mean value and standard deviation (SD). Comparisons between athletes and controls, between HI, MI, and LI sports, and between participants and dropouts were carried out using two sample Student's *t* test for continuous data and χ^2 test for categorical data. Differences were considered statistically significant for p values equal to or less than 5%. Linear regression analysis was conducted to investigate the relationship between BMD and a set of risk factors, and univariate analysis of variance was used to adjust for key variables between athletes and controls.

Definitions of low BMD

We defined the various levels of BMD using t scores in two ways: (i) according to the reference material supplied by the manufacturer,[19] and (ii) from a random sample of Norwegian control participants. In accordance with the World Health Organization,[20] we classified the females as osteoporotic if their BMD t score compared with either Lunar or Norwegian norms was below -2.5 and osteopenic if their BMD t score was between -1 and -2.5. However, due to the insufficient data regarding the relationship between BMD and fracture risk, resulting in difficulties defining osteopenia and osteoporosis in premenopausal women,[21] we mainly use the term ''low BMD'' instead of ''osteopenia'' or ''osteoporosis''. Thus, low BMD used in this study is defined as a t score <-1.0. In reporting data on the prevalence of low BMD, any diagnosis of low BMD in at least one of five measurement areas (TB, lumbar spine (L_2-L_4), femur neck, femur trochanter, or total femur) was included. Only females over 20 years of age were included in these results.

Table 1 Classification of 46 sports (n = 186) divided into three groups based on the degree of mechanical loading in the sport

Low impact* (n = 38)	Medium impact† (n = 51)	High impact‡ (n = 97)
Billiard (n = 1)	Ski orienteering (n = 2)	Gymnastics (n = 16)
Bowling (n = 3)	Triathlon (n = 1)	Track and field (sprint events) (n = 4)
Climbing (n = 3)	Kickboxing (n = 1)	Rhythmic gymnastics (n = 17)
Curling (n = 1)	Table tennis (n = 2)	Tennis (n = 1)
Cycling (n = 4)	Paddling (n = 1)	Power lifting (n = 2)
Dog racing (n = 2)	Judo (n = 1)	Basketball (n = 6)
Horseback riding (dressage) (n = 3)	Race walking (n = 2)	Team handball (n = 14)
Shooting (n = 3)	Middle and long distance running (n = 6)	Volleyball (n = 6)
Swimming (n = 6)	Rowing (n = 3)	Alpine skiing (n = 1)
Underwater rugby (n = 12)	Sailing (n = 3)	Telemark skiing(n = 1)
	Sports dance (n = 4)	Badminton (n = 3)
	Karate (n = 1)	Figure skating (n = 1)
	Biathlon (n = 2)	Ice hockey (n = 1)
	Track and field (throwing events) (n = 1)	Soccer (n = 17)
	Cross-country skiing (n = 3)	Speed skating sprint (n = 2)
	Field hockey (n = 8)	Track and field (jumping events) (n = 4)
	Wrestling (n = 1)	Freestyle (n = 1)
	Long-distance speed skating (n = 1)	
	Orienteering (n = 8)	

*Includes non-weight bearing sports or sports with low mechanical loading.
†Includes weight bearing sports and sports with moderate mechanical loading. Sports including elements of sprinting and turning actions are included in this group.
‡Includes weight bearing sports with high mechanical loading. Sports where jumping activities and/or rapid movements are widespread are included in this group.

Table 2 Anthropometric data and unadjusted and adjusted BMD in athletes (n = 186) and controls (n = 145)

	Athletes	Controls	p Value
Anthropometric data			
Age (years)	22.2 (5.8)	29.6 (7.9)	p<0.001
Weight (kg)	61.5 (8.7)	66.4 (12.3)	p<0.001
Height (cm)	168.1 (6.9)	166.2 (6.3)	p<0.01
BMI (kg/m^2)	21.7 (2.4)	24.0 (4.2)	p<0.001
BMD (g/cm^2)			
Total body			
Unadjusted	1.21 (0.09)	1.18 (0.08)	p<0.001
Adjusted for age, height, and weight	1.22 (0.08)	1.17 (0.08)	p<0.001
Adjusted for age, height, weight, and LBM	1.21 (0.08)	1.19 (0.08)	p<0.05
Lumbar spine (L_2–L_4)			
Unadjusted	1.30 (0.15)	1.24 (0.13)	p<0.001
Adjusted for age, height, and weight	1.30 (0.15)	1.24 (0.16)	p<0.001
Adjusted for age, height, weight, and LBM	1.28 (0.16)	1.27 (0.17)	NS
Total femur			
Unadjusted	1.16 (0.14)	1.05 (0.12)	p<0.001
Adjusted for age, height, and weight	1.16 (0.14)	1.06 (0.15)	p<0.001
Adjusted for age, height, weight, and LBM	1.13 (0.15)	1.09 (0.16)	p<0.05

LBM, lean body mass. Data are given as mean (SD).

RESULTS

Subject characteristics

The athletes were younger and had lower BMI values than the controls ($p<0.001$) (table 2). The mean (SD) age of athletes competing in LI (24.3 (6.6) years old) and MI (23.7 (5.4) years old) sports was higher than that of athletes competing in HI sports (20.5 (5.2) years old) ($p<0.001$). There were no significant differences in BMI between the sport groups.

The athletes trained an average of 13.9 (5.6) h per week. Physical activity reported by the controls was 5.3 (5.3) h per week, with 3.8 h per week being WBA and 1.6 h per week being NWBA.

BMD

BMD was higher at all measurement sites in athletes compared to controls (table 2) and in athletes competing in HI sports compared with athletes competing in LI and MI sports (table 3). Similarly, athletes competing in MI sports generally had greater BMD than athletes competing in LI sports (table 3).

Athletes competing in MI and HI sports had higher BMD than controls in all measurement areas ($p<0.001$ to $p<0.01$) except lumbar spine and TB ($p = 0.06$) for the MI sport group, and LI sport athletes had higher femur trochanter and Ward's triangle BMD than controls ($p<0.05$).

Determinants of BMD

Of the variation in TB BMD in the athletes and the controls, 47.6% and 25.4%, respectively, were explained by the models presented in tables 4 and 5.

Prevalence of low BMD

Eleven percent of the athletes and 28% of the controls were diagnosed with low BMD in at least one of the five measurements sites ($p<0.001$). Of these subjects, none of the athletes and two of the controls were diagnosed with osteoporosis. When the prevalence was calculated based on the Lunar reference material, 9% of the athletes and 18% of the controls had low BMD, including one control with osteoporosis.

A higher percentage of controls than athletes were diagnosed with low TB BMD (15.0% *v* 4.9%, respectively) and low total femur BMD (15.0% *v* 2.9%, respectively) ($p<0.01$). There was no difference in the prevalence of low lumbar spine BMD (15.0% and 7.8% in controls and athletes, respectively).

Influence of MD and EDs on BMD

Controls with MD had lower TB, total femur, and lumbar spine BMD than controls without MD. Athletes with EDs had lower TB and lumbar spine BMD than athletes without EDs (table 6). Athletes with MD participating in HI sports had higher BMD in all measurement sites than athletes with MD competing in LI sports and MI sports ($p<0.001$ to $p<0.05$).

Dropout analysis

In the control group, no differences were found between participants and dropouts in terms of age, body weight, BMI, WBA, previous pregnancy, smoking habits, use of medications that may affect bone health, MD, prevalence of stress fractures, oral contraceptive use, or self reported EDs. The dropouts were, however, taller (168.2 (6.0) cm) than the participants (166.1 (6.3) cm) ($p<0.05$).

Table 3 BMD in athletes competing in low impact, medium impact, and high impact sports

BMD (g/cm^2)	LI sports (n = 38)	MI sports (n = 51)	HI sports (n = 97)
Total body	1.17 (0.06)	1.20 (0.07)*	1.24 (0.10)‡
Lumbar spine (L_2–L_4)	1.22 (0.12)	1.24 (0.15)	1.35 (0.16) ‡
Total femur	1.08 (0.10)	1.12 (0.14)	1.22 (0.13) ‡
Femur neck	1.05 (0.09)	1.12 (0.14)*	1.23 (0.13) ‡
Ward's triangle	0.97 (0.10)	1.05 (0.18)†	1.18 (0.16) ‡
Femur trochanter	0.88 (0.09)	0.91 (0.13)	1.03 (0.12) ‡
Femur shaft	1.26 (0.13)	1.30 (0.16)	1.39 (0.18) ‡

The significance level of differences between the groups is age adjusted using linear regression analysis. Data are given as mean (SD). HI, high impact; LI, low impact; MI, medium impact.
*$p<0.01$ compared with LI sports; †$p<0.05$ compared with LI sports; ‡$p<0.001$ compared with LI and MI sports.

Table 4 Determinants of total body, total femur, and lumbar spine BMD (g/cm^2) from backward stepwise multiple regression models in the athletes (n = 186)

Site	MD	EDs	Body fat (%)	Sport groups	Weight (kg)	R^{2*}
Total body	NS	$p<0.05$	$p<0.01$	$p<0.001$	$p<0.001$	0.48
β (SE)	–	−0.023 (0.010)	−0.003 (0.001)	0.043 (0.007)	0.007 (0.001)	
Total femur	NS	NS	NS	$p<0.001$	$p<0.01$	0.27
β (SE)	–	–	–	0.086 (0.012)	0.003 (0.001)	
Lumbar spine	$p<0.05$	NS	$p<0.01$	$p<0.001$	$p<0.001$	0.37
β (SE)	−0.043 (0.021)	–	−0.004 (0.002)	0.077 (0.013)	0.009 (0.001)	

Adjusted R square (R^2) for the final model for each measurement site is presented. Significance levels are shown, followed on the line beneath by unstandardised β coefficients (β) and standard error (SE).
*Age of sport specialisation (when they started competing in their sport), smoking, height, oral contraceptive use, use of medications that can affect bone metabolism, and menarche were not significantly associated with BMD and are therefore not included in the table or in the R^2 value.
EDs, eating disorders; MD, menstrual dysfunction; NS, not significant. Sport groups are classified into low impact, medium impact and high impact sports.

Among the athletes, no differences were found between the participants and the dropouts in terms of age, age of sport specialisation, training volume, height, smoking habits, use of medications that may affect bone health, prevalence of stress fractures, national or international ranking performance, or oral contraceptive use. The participants had, however, a lower body weight and BMI compared with the dropouts ($p<0.01$). A higher percentage of the participants than the dropouts reported MD and self reported EDs. In addition, a lower percentage of participants compared with dropouts reported previous pregnancy ($p<0.05$).

DISCUSSION

BMD

In accordance with other studies,[4–7 22–24] we found a higher BMD in athletes compared with non-athletic controls, and further, in agreement with biomechanical principles[15] and previous studies that examined a selection of sports,[22 24 25] our results showed that BMD was higher in all measurement sites in athletes competing in HI sports than in athletes competing in LI and MI sports. In addition, our results support other findings[22 24–26] in that not all athletic groups derive a sport associated BMD benefit.

It should be noted that it is possible that rather than the training itself leading to an increase in BMD, the high BMD in some of these athletes may simply reflect a genetically predetermined strong musculoskeletal system, which favours the participation of these women in higher impact sports. An argument against this hypothesis comes from studies of asymmetric activities, such as tennis or squash, where the playing arm has a greater bone mass than the non-playing arm.[27 28]

Determinants of BMD

It has been reported that WBA can protect against the negative effects of MD on bone density.[11 29] However, Pearce *et al*[30] concluded that WBA exercise is unlikely to offset the deleterious effects of oligomenorrhea on bone. In the present study, MD was associated with reduced lumbar spine BMD in the athletes, but no difference in BMD between athletes with or without MD was found. In the athlete group, participation in impact loading sports, percent body fat, and body weight seem to be more important factors than MD in terms of effect on bone mass. However, athletes with MD participating in HI sports had higher BMD in all measurement sites than athletes with MD competing in LI sports and MI sports, which may imply a possible protective effect of HI exercise on bone in athletes with MD. The negative influence of EDs and/or nutritional deficiency on bone has recently been shown in runners,[9 31] and was further supported by data from our study showing that athletes with EDs had 3–5% lower TB and lumbar spine BMD compared with athletes without EDs.

In contrast to the athletes, MD was negatively associated with all three measurement sites in the controls. In addition, controls with MD had 3–6% lower BMD in the hip, spine, and TB than controls without MD. Our results are consistent with the hypothesis that the WBA engaged in by the controls may not be sufficient to offset the negative effects of MD on BMD, while participation in MI and/or HI sports at the elite level protect to a higher degree against loss of bone mass caused by MD.

Prevalence of low BMD

In a young healthy population, 15% of women will be diagnosed with osteopenia and approximately 0.5% will be diagnosed with osteoporosis.[32] According to this, fewer athletes than expected and more controls than expected were diagnosed with low BMD in our study. However, when we look at the prevalence of low BMD in the different measurement areas, our results were more in accordance with the expected prevalence: 15–17% of the controls were diagnosed with low BMD in total femur, TB, or lumbar spine, though the prevalence of low BMD in athletes was much lower, between 3 and 8% in the same measurement areas.

Table 5 Determinants of total body, total femur, and lumbar spine BMD (g/cm^2) from backward stepwise multiple regression models in the controls (n = 145)

Site	MD	WBA	Age (years)	Height (cm)	Weight (kg)	R^{2*}
Total body	$p<0.05$	$p<0.01$	NS	NS	$p<0.001$	0.25
β (SE)	−0.026 (0.013)	0.00007 (0.000)	–	–	0.003 (0.000)	
Total femur	$p<0.01$	$p<0.05$	$p<0.001$	NS	$p<0.01$	0.20
β (SE)	−0.059 (0.022)	0.0001 (0.000)	−0.005 (0.001)	–	0.003 (0.001)	
Lumbar spine	$p<0.05$	NS (p = 0.065)	NS	$p<0.05$	NS	0.06
β (SE)	−0.054 (0.026)	0.0011 (0.000)	–	0.004 (0.002)	–	

Adjusted R square (R^2) for the final model for each measurement site is presented. Significance levels are shown, followed on the line beneath by unstandardised β coefficients (β) and standard error (SE).
*Smoking, oral contraceptive use, use of medications that can affect bone metabolism, eating disorders, menarche, and body fat (%) were not significantly associated with BMD and are therefore not included in the table or in the R^2 value.
MD, menstrual dysfunction; NS, not significant; WBA, weight bearing physical activity.

Table 6 BMD in athletes with (n = 80) or without (n = 106) menstrual dysfunction and with (n = 79) or without (n = 107) eating disorders and BMD in non-athletic controls with (n = 39) or without (n = 106) menstrual dysfunction and with (n = 46) or without (n = 99)

	MD		EDs	
BMD (g/cm^2)	Yes	No	Yes	No
Total body				
Athletes	1.21 (0.07)	1.22 (0.10)	1.19 (0.08)‡	1.23 (0.09)
Controls	1.16 (0.08)*	1.19 (0.07)	1.18 (0.08)	1.18 (0.08)
Total femur				
Athletes	1.15 (0.13)	1.18 (0.14)	1.14 (0.13)	1.18 (0.15)
Controls	1.00 (0.13)†	1.06 (0.12)	1.05 (0.12)	1.05 (0.12)
Lumbar spine				
Athletes	1.27 (0.15)	1.31 (0.16)	1.25 (0.16)§	1.32 (0.15)
Controls	1.21 (0.12)*	1.26 (0.13)	1.25 (0.14)	1.24 (0.13)

Data are presented as mean values (SD) in TB, total femur, and lumbar spine. ED, eating disorder; MD, menstrual dysfunction.
*$p<0.05$ compared with no MD; †$p<0.01$ compared with no MD; ‡$p<0.001$ compared with no EDs; §$p<0.01$ compared with no EDs.

Considering these results, it may be possible that athletes have a lower prevalence of low BMD compared with a normally distributed population of premenopausal women. Nevertheless, few data[33] exist on the long term effects on BMD after cessation of elite competition.

We found a higher prevalence of low BMD in both athletes and controls compared with American female soldiers,[10] but a lower prevalence compared with ballet dancers and runners.[9 11–13] However, these studies included only athletes with MD in one single sport, while we included elite level athletes with and without MD in all kinds of sports. Also, those studies were subject to greater risk of ascertainment bias than our controlled population based study.

Overall, using the prevalence based on the Lunar reference material,[19] fewer women were diagnosed with low BMD, which suggests that BMD in the control group used in this study was higher than that of the volunteers on whom the Lunar software is based.

Generalisation of the results

Despite the known possible limitations of cross sectional studies (that is, self selection, inadequate sampling methods, and a volunteer effect), the prevalence results from this study seem generalisable to female elite athlete populations and to non-athletic premenopausal women in general. It should be noted, however, that our comparison of athlete participants and dropouts indicates that a higher frequency of athletes at risk for the female athlete triad participated in parts II and III of this study compared with the dropouts. Therefore, the prevalence of low BMD in the total population of female elite athletes is presumably no higher than that reported in the present study. Studies evaluating the relationship between BMD and fracture risk in premenopausal women are needed to more accurately determine the definition of low BMD in this group.

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What is already known on this topic

Weight bearing exercise has been shown to reduce bone loss and increase bone mass. Studies have shown that athletes have about 10% greater bone mineral density (BMD) than non-athletes.

What this study adds

Participation in weight bearing exercise and/or activity with medium or high impact loading on the skeleton is associated with increased BMD in young women, and may somewhat protect against bone loss due to menstrual or eating disorders. However, low BMD is present in both elite athletes and in non-athletic females.

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COMMENTARY

The paper by Torstveit and Sundgot-Borgen[1] provides a useful addition to the body of evidence relating bone mineral measures to type of sporting activity and comparing these measures between athletes and less active controls. Despite some methodological limitations, this paper shows quite persuasively that areal bone mineral density (BMD) measures are higher in athletes the greater is the level of impact in their sporting activity. Moreover, medium and high impact sports, but apparently not low impact sports, appear to convey a BMD advantage compared with non-participation in sport at an elite level. Of particular interest, athletes classified as having menstrual disorders or eating disorders appeared not to have a BMD deficit relative to controls. This information provides some reassurance concerning the bone health of athletes with these disorders. However, the provision of more information would have been helpful. Description of the interactive effect on BMD of menstrual/eating disorders and impact level of sporting activity would be important to give the findings clinical relevance. In particular, what is the effect of menstrual and eating disorders on BMD measures (especially at the lumbar spine) in practitioners of lower impact sports? Other information that would add to this study includes the age of commencement of substantial sporting activity, since this is probably a major determinant of the BMD advantage observed in athletes compared with non-athletic individuals.[2 3] Looking to the future, long term follow up of these cohorts also would be of great value.

Finally, it is now time to move beyond merely measuring areal BMD if we are to achieve a deeper understanding of the effects of environmental exposures such as physical activity on long term bone-related health outcomes. Bone strength, not areal BMD, is the organ characteristic of relevance to skeletal health outcomes and a number of investigational tools are now available to enable its evaluation. Some good work has been done already in this area. Application of techniques such as hip structural analysis,[4] magnetic resonance imaging,[5] and peripheral quantitative computed tomography[6] is needed to elucidate effects of physical activity on bone geometry and microstructure as indices of bone strength. Other parameters of bone ''quality'' also invite exploration. There is still much to learn about the response of bone to mechanical loading and it is time to apply the newer technologies in our human research in this field.

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