Bone mineral density and body composition of the United States Olympic women's field hockey team

Phillip B Sparling, Teresa K Snow, Linda B Rosskopf, Elizabeth M O'Donnell, Patty S Freedson, William C Byrnes

Abstract

***Objective*—To evaluate total bone mineral density (BMD) and body composition (% fat) in world class women field hockey players, members of the 1996 United States Olympic team.**

***Methods*—Whole body BMD (g/cm^2) and relative body fatness (% fat) were assessed by dual energy *x* ray absorptiometry using a Lunar DPX-L unit with software version 1.3z. Body composition was also estimated by hydrostatic weighing and the sum of seven skinfolds.**

***Results*—Mean (SD) BMD was 1.253 (0.048) g/cm^2 which is 113.2 (4.0)% of age and weight adjusted norms. Estimates of body composition from the three methods were similar (statistically non-significant): 16.1 (4.4)% fat from dual energy *x* ray absorptiometry, 17.6 (3.2)% from hydrostatic weighing, and 16.9 (2.6)% from the sum of seven skinfolds. Mean fat free mass was approximately 50 kg.**

***Conclusions*—The mean whole body BMD value for members of the 1996 United States Olympic women's field hockey team is one of the highest reported for any women's sports team. Moreover, the mean fat free mass per unit height was quite high and % fat was low. In this group of world class sportswomen, low % fat was not associated with low BMD.**

(*Br J Sports Med* 1998;**32**:315–318)

Keywords: bone mineral density; body composition; body fatness; female athletes; sportswomen

Department of Health and Performance Sciences, Georgia Institute of Technology, Atlanta, GA, USA
P B Sparling
T K Snow
L B Rosskopf
E M O'Donnell

Department of Exercise Science, University of Massachusetts at Amherst, MA, USA
P S Freedson

Department of Kinesiology, University of Colorado at Boulder, CO, USA
W C Byrnes

Correspondence to:
Dr P B Sparling, Georgia Institute of Technology, Health and Performance Sciences, Atlanta, GA 30332–110, USA.

Accepted for publication 23 June 1998

At the international level, in addition to refinement of sports skills and development of team cohesiveness, the sport of field hockey requires a high level of physical fitness. To reach this competitive level, players must adhere to a rigorous training programme for many years. Yet, a growing concern among sportswomen is the potential detrimental effect of long term heavy training on their bone health.[1]

Premature bone loss and high rates of stress fracture were first reported in female distance runners.[1] Women in endurance sports or sports that emphasise low body weight or are weight regulated appear to be most vulnerable. The principal cause of premenopausal osteoporosis in sportswomen is hypo-oestrogenaemia as a result of hypothalamic amenorrhoea.[1] Disordered eating and/or excessive exercise, concurrent with a lowering of body weight and body fat, may induce the amenorrhoeic condition.

Since the introduction of bone densitometers based on dual energy *x* ray absorptiometry (DXA) in 1988–1990, the frequency of bone mineral assessment has increased markedly in medical centres and universities world wide. DXA measurements are safe[2] (radiation exposure of 1–2 mrem for a whole body scan) and time efficient (5–30 minutes). DXA technology can also differentiate fat mass from non-bone lean tissue mass and consequently is increasingly used as a method for evaluating body composition.

Although women's field hockey is a popular international sport, limited data have been reported on the bone mineral and body composition status of these athletes. Therefore the aim of this study was to asses bone mineral density (BMD) and % fat in the 1996 United States Olympic women's field hockey team.

Methods

SUBJECTS

The subjects for this study were 12 members of the USA Olympic women's field hockey team. The team resided in Atlanta for the 12 months preceding the 1996 Olympic Games to focus on training and preparation for the forthcoming competition. All players had outstanding college credentials, had been named to National Team squads (first year selections ranged from 1988 to 1994), and had international experience (from 19 to 121 matches with a mean of 57).

PROTOCOL

These sportswomen were seen in our laboratory in April 1996. All measurements were performed during one session. Written informed consent was obtained from each woman. Information on personal health, training programmes, and menstrual cycle history were obtained by questionnaire and followed up by interview. Each woman also completed a 24 hour history form which requested information on diet, sleep, and exercise. Standing height was measured to the nearest centimetre using a wall stadiometer, and body weight was measured to the nearest 0.1 kg on a Chatillon model H81000 platform scale (Wiggins Scale Co, Atlanta, Georgia, USA). The testing sequence was (1) skinfolds, (2) DXA, and (3) hydrostatic weighing.

SKINFOLDS

Skinfolds were taken on the right side with a Lange caliper (Creative Health Products, Plymouth, Michigan, USA) by the same experienced investigator. Seven sites were measured as described by Jackson *et al*[3]: chest, axilla, triceps, subscapular, abdominal, suprailiac, and thigh. Body density was estimated from the regression equation which uses the sum of the seven

Table 1 Physical characteristics of women on the 1996 US Olympic field hockey team

No	Age (y)	Height (m)	Weight (kg)	BMI (kg/m²)
1	29	170	67.2	23.3
2	29	151	54.1	23.7
3	26	175	58.0	18.9
4	21	168	61.4	21.8
5	27	160	56.9	22.2
6	27	163	57.9	21.8
7	28	163	59.5	22.4
8	26	163	57.6	21.7
9	31	166	65.0	23.6
10	26	166	57.5	20.9
11	25	166	60.4	21.9
12	26	165	60.1	22.1
Mean	27	165	59.6	22.0
SD	3	6	3.6	1.3

BMI, body mass index.

Table 2 Dual energy x ray absorptiometry (DXA) measurements using a Lunar DPX-L in elite female field hockey players

No	BMD (g/cm²)	NORM (%)	BMC (kg)	BMC/FFM
1	1.253	111	2.897	0.0521
2	1.240	114	2.441	0.0542
3	1.239	112	2.877	0.0559
4	1.180	106	2.629	0.0541
5	1.230	112	2.601	0.0521
6	1.240	113	2.753	0.0571
7	1.250	113	2.822	0.0545
8	1.281	116	2.827	0.0552
9	1.374	122	3.326	0.0680
10	1.274	116	2.819	0.0582
11	1.204	109	2.719	0.0573
12	1.267	114	2.847	0.0541
Mean	1.253	113	2.797	0.0561
SD	0.0475	4	0.0214	0.0042

BMD, bone mineral density; BMC, bone mineral content; FFM, fat free mass.

skinfolds, the sum squared, and age as predictor variables. Percentage fat was calculated from body density using the Siri equation.[4] This two component model assumes that the density of the fat free mass (FFM) is 1.100 g/cm^3.

HYDROSTATIC WEIGHING

Body density was determined by the method of Goldman and Buskirk.[5] Underwater weight was measured to the nearest 0.05 kg from a Chatillon scale (model 15–25). Using a nitrogen analyser (Nitralyzer model 505; Kae Tech Instruments, Suatnico, Wisconsin, USA), residual lung volume was determined simultaneously with underwater weighing by the closed circuit oxygen dilution method described by Wilmore.[6] As with the skinfold method, the Siri equation was used to convert body density to % fat.

DXA

Total BMD expressed as an area density (g/cm^2), bone mineral content (BMC, g), and % fat were estimated from whole body scans on a Lunar DPX-L unit (Lunar, Madison, Wisconsin, USA). These measurements were derived using Lunar's proprietary software, version 1.3z with extended research analysis. For consistency, one trained technician positioned the subjects, conducted the scans, and performed the follow up analyses. All subjects were scanned using medium mode. The Lunar DPX-L unit was calibrated daily according to the manufacturer's instructions using a standard calibration block which consisted of a thermoplastic acrylic resin housing with three bone-equivalent chambers containing hydroxyapatite. The coefficient of variation was <1.14% for all calibrations over a 15 month period.

STATISTICAL ANALYSIS

Statistical analyses were carried out with SAS for Windows version 6.08 (SAS Institute, Cary, North Carolina, USA). Means (SD) for variables of interest were calculated. Pearson correlations were also computed to examine selected associations. A one way analysis of variance was used to test for mean differences across the three estimates of % fat. p was set at ≤ 0.05 for all significance tests.

Results

Table 1 gives the individual physical characteristics of the United States Olympic women's field hockey players. Height, weight, and body mass index (BMI) for these 12 white sportswomen were within normal ranges for young adult women and unremarkable in themselves. The mean (SD) values are similar to those for a group of 121 healthy white women previously studied in our laboratory[7]: age 28 (6) years, height 166 (7) cm, weight 59.5 (7.8) kg, and BMI 21.6 (2.2) kg/m^2.

Table 2 gives a summary of DXA measurements. Mean BMD was 113.2% of the age- and weight-matched normative data.[8] Values for BMC in kg and as a decimal fraction of FFM are also presented. The small SDs for each of these variables reflect the low variability for these measurements in this group of elite players.

In table 3, individual % fat estimates are summarised. No statistically significant differences were observed among the mean body fat values obtained by DXA (16.1%), hydrostatic weighing (17.6%), or skinfolds (16.9%). Pearson correlations among the three methods were reasonably high (DXA-hydrostatic weighing, 0.87; DXA-skinfolds, 0.91; hydrostatic weighing-skinfolds, 0.74) considering the small sample size and homogeneity of the sample. Among the 12 players the sum of seven skinfolds ranged from 50 to 115 mm with a mean (SD) of 79 (17) mm.

The quality and quantity of physical training engaged in by these sportswomen was extremely high. For the preceding three months, they had trained as a team for three to four hours a day, six days a week. Their physical conditioning programme included field drills and scrimmages, interval training, resistance training, stretching, and calisthenics. The training regimen included both moderate and

Table 3 Body composition (% fat) measurements in elite female field hockey players

No	DXA	HW	SF
1	17.2	19.7	17.8
2	16.8	17.3	18.6
3	11.3	14.8	12.3
4	20.9	22.7	19.2
5	12.3	15.7	15.1
6	16.8	16.6	17.3
7	12.9	15.0	16.4
8	11.1	15.7	15.2
9	24.7	20.3	22.5
10	15.7	15.5	16.4
11	21.5	22.7	17.9
12	21.4	14.4	14.2
Mean	16.1	17.6	16.9
SD	4.4	3.2	2.6

DXA, dual energy *x* ray absorptiometry; HW, hydrostatic weighing; SF, skinfolds.

high impact exercise. Their mean (SD) aerobic capacity has been reported[9] as 57.1 (2.7) ml/min/kg. As previously noted, all of these field hockey players had competed at international level for two years or more.

Results from the menstrual history survey completed by 11 of the 12 women indicate that the mean (SD) age of menarche was 13.7 (1.7) years. Three players were eumenorrhoeic and had always had normal cycles. The remaining eight responded positively to the question: Have you ever experienced irregular menstrual cycles where you have had less than nine periods a year? On follow up, two of the eight reported having experienced secondary amenorrhoea (less than four menses/year) in previous years. For the preceding 12 months, the mean number of menses missed for these eight women was 3.4 with a range of 0 to 8. Consequently, based on the previous year, seven of the women were eumenorrhoeic and four were oligomenorrhoeic. Three of the 11 women were currently taking oral contraceptives, one for medical reasons.

Discussion

The primary contribution of this descriptive study is the profiling of the bone mineral and body composition status in an elite women's field hockey team. The mean whole body BMD value for members of the 1996 United States Olympic women's field hockey team is one of the highest reported for any women's sports team (1.253 (0.048) g/cm^2). This value is 13% higher than age and weight adjusted norms and 1.8 SDs above the normative value for a 59 kg woman, 27 years of age.[8] Each of the12 players had an above average value; individual values ranged from 106 to 122% of the normative value.

Results from numerous studies suggest that premenopausal women who participate regularly in high impact exercise tend to have higher BMD than sedentary controls.[10–13] For example, in female senior football (soccer) players (n = 34), whole body BMD was 3.5% higher than matched controls (n = 90).[10] Whole body BMD in 13 high level female volleyball players was 6.1% higher than 13 matched non-active women.[11] In general, the differences in BMD between highly trained athletes in weight loading sports and sedentary women have been consistent but relatively small.

Differences in BMD values measured at specific sites or for the total body have been reported when equipment from different manufacturers[14]—for example, Lunar DPX-L *v* Hologic QDR 1000W—and different software packages from the same manufacturer[15]—for example, Lunar 3.4 *v* 3.6z—have been used. Since absolute values may vary slightly with hardware and software changes, each manufacturer has established a reference to assist in diagnosis and interpretation. When comparing DXA results with those of other researchers and clinicians, it is important to note that values may not be directly comparable unless the same instrument (manufacturer and model) and software version have been used.[2 16]

Using the same model Lunar DXA unit and compatible software, Madsen *et al*[17] reported mean whole body BMD in 20 eumenorrhoeic intercollegiate athletes (age 21 years, height 165 cm, weight 52.3 kg, BMI 19.1 kg/m^2) to be 1.164 (0.06) g/cm^2. Although all subjects were involved in weight bearing sports including gymnastics, soccer, volleyball, track and field, and cross-country, the mean BMD was clearly lower than that found in the field hockey players. A portion of this difference could be attributable to the lower body weight of the college athletes (52.3 *v* 59.6 kg). However, in 20 average weight (62.0 kg) sedentary controls, mean BMD was 1.138 (0.07) g/cm^2, which is similar to the low weight athletes.[17] In this comparison, a high level of physical training and low body weight appears to be counterbalanced by a low level of physical activity and a higher body weight.

Total BMC (kg) in the field hockey players was 14.6% higher than for the low weight college athletes and 12.3% higher than for the sedentary controls.[17] BMC expressed as a fraction of FFM (BMC/FFM) was similar for all three groups (0.056, 0.054, and 0.055 respectively). Thus the field hockey players had both high BMC and high FFM. (Mean (SD) FFM was 49.9 (2.8) kg in the elite players, 45.0 (3.9) in the college athletes, and 45.0 (3.7) in the sedentary controls.)

Premature bone loss has been reported in sportswomen including distance runners, gymnasts, and dancers among others.[1] This condition is thought to be caused primarily by amenorrhoea which may be induced in some women by high volume physical training, low caloric intake, poor diet, and/or disordered eating. Low body weight and body fat are also often associated with this premenopausal osteoporosis.

In the preceding 12 months, none of the 12 women in this study were known to be amenorrhoeic: seven were categorised as eumenorrhoeic, four as oligomenorrhoeic, and one did not report. All three women taking oral contraceptives were eumenorrhoeic: two of the three had previously been oligomenorrhoeic. The volume and intensity of training was indeed quite high in absolute terms (20–24 hours a week) but not unusual for an international team in this sport. No information was collected on dietary behaviour. However, eating disorders are generally associated with sports that encourage low body weight—for example, running and cycling—have weight classes—for example, rowing and martial arts—or are subjectively judged—for example, gymnastics, diving, and figure skating. As the sport of field hockey is not directly constrained by these factors, we would speculate that the prevalence of eating disorders would be lower than in the aforementioned sports.

Estimates of relative body fatness by skinfolds, hydrostatic weighing, and DXA were similar, with mean values ranging from 16.1 to 17.6%. The regression equation developed by Jackson *et al*[3] for predicting body density from the sum of seven skinfolds has been found to be valid for women in different sports.[18] This generalised prediction equation was also found to be valid in our homogeneous group of women field hockey players.

DXA and hydrostatic weighing are competing reference methods, each with its own unique set of assumptions and limitations.[2 16 19] In a recent in vivo validation study using a four component model (the current gold standard), body composition estimates from both DXA and hydrostatic weighing were found to be accurate in young women who varied in athletic status and body size.[20] Our results are in agreement with these findings.

On the basis of hydrostatic weighing in our laboratory, lower body fat estimates (14.3 (3.3)%) were observed in 15 elite women distance runners of similar age (mean 28 years).[21] By team or sport, the leanest sportswomen are generally also the lightest, as was the case with the elite women distance runners whose mean body weight was 47.2 kg. Twelve club level distance runners (mean age 29 years) with a slightly higher average body weight of 49.4 kg had a mean body fat of 16.8 (5.3)%.[21] This % fat level is similar to that of the field hockey players whose mean body weight was 10 kg higher.

Some investigators have combined DXA and hydrostatic weighing methods into a three component model in which % fat is estimated by correcting body density (from hydrostatic weighing) for individual variation in bone mineral (from DXA).[17] This model is limited because it is incomplete; the total body water component is not measured. Recent research using a four component model indicates that the greatest variability in FFM is associated with the total body water component, not the bone mineral component.[22] Owing to the selective effects exercise training can have on bone mineral and total body water components, it is no longer advisable to combine measurement methods unless all components can be determined—that is, body density, bone mineral, and total body water.

A striking characteristic of the body composition findings for these elite field hockey players is their high FFM. Whether hydrostatic weighing or DXA were used as the reference method, the mean FFM approaches 50 kg (49.1 (2.5) or 49.9 (2.8) kg). Hydrostatic weighing assessments in 121 physically active white women, 62 of whom exercised for two hours or more a week, yielded a mean % fat and FFM of 24.3 (5.6)% and 44.8 (5.3) kg respectively.[7] The field hockey players had a mean FFM 10% higher than these women of similar age, height, and weight (28 years, 166 cm, and 59.5 kg respectively). The high FFM per unit height ratio observed in the elite sportswomen, attributable to rigorous training and genetic influence, is associated with their high bone mineral values.[23 24]

In summary, it is evident that mechanical loading of the skeleton is beneficial to bone health in eumenorrhoeic women. This osteogenic effect of impact loading through sports training, however, generally has been found to be modest. Sportswomen in high impact sports like gymnastics, volleyball, and basketball have whole body BMDs that are 2–6% higher than age and weight matched sedentary controls. The mean whole body BMD for members of the 1996 United States Olympic women's field hockey team was 13% higher than normative standards. This BMD is one of the highest reported for any women's sports team. Moreover, their mean FFM was quite high while mean % fat was low. The excellent bone mineral and body composition status of these elite sportswomen is probably associated with the combination of long term rigorous physical training and favourable genetic predisposition.

1 Otis CL, Drinkwater B, Johnson M, *et al*. ACSM position stand on the female athlete triad. *Med Sci Sports Exerc* 1997;**29**:i–ix.
2 Lohman TG. Dual energy x-ray absorptiometry. In: Roche AF, Heymsfield SB, Lohman TG, eds. *Human body composition*. Champaign, IL: Human Kinetics, 1996:63–78.
3 Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body density of women. *Med Sci Sports* 1980;**12**: 175–82.
4 Siri WE. Body composition from fluid spaces and density: analysis of methods. In: Brozek J, Henshel A, eds. *Techniques for measuring body composition.* Washington, DC: National Academy of Science, 1961:223–44.
5 Goldman RF, Buskirk ER. Body volume measurement by underwater weighing: description of a method. In: Brozek J, Henshel A, eds. *Techniques for measuring body composition.* Washington, DC: National Academy of Science, 1961:77–89.
6 Wilmore JH. A simplified method for determination of residual lung volumes. *J Appl Physiol* 1969;**27**:96–100.
7 Sparling PB, Millard-Stafford M, Rosskopf LB, *et al*. Body composition by bioelectric impedance and densitometry in black women. *American Journal of Human Biology* 1993;**5**: 111–17.
8 Lunar Corporation. Appendix C: comparison to reference populations. In *Lunar DPX-L technical manual.* Madison, WI: Lunar Corporation, 1993:C1–11.
9 Melanson E, Freedson PS, Byrnes WC, *et al*. A laboratory and field study of the U.S. Olympic women's field hockey team. [Abstrac] *Med Sci Sports Exerc* 1997;**29**:S224.
10 Düppe H, Gärdsell P, Johnell O, *et al*. Bone mineral density in female junior, senior and former football players. *Osteoporos Int* 1996;**6**:437–41.
11 Alfredson H, Nordström P, Lorentzon R. Bone mass in female volleyball players: a comparison of total and regional bone mass in female volleyball players and nonactive females. *Calcif Tissue Int* 1997;**60**:338–42.
12 Dook JE, James C, Henderson NK, *et al*. Exercise and bone mineral density in mature female athletes. *Med Sci Sports Exerc* 1997;**29**:291–6.
13 Taaffe DR, Robinson TL, Snow CM, *et al*. High-impact exercise promotes bone gain in well-trained female athletes. *J Bone Miner Res* 1997;**12**:255–60.
14 Modlesky CM, Lewis RD, Yetman KA, *et al*. Comparison of body composition and bone mineral measurements from two DXA instruments in young men. *Am J Clin Nutr* 1996; **64**:669–76.
15 VanLoan MD, Keim NL, Berg K, *et al*. Evaluation of body composition by dual energy x-ray absorptiometry and two different software packages. *Med Sci Sports Exerc* 1995;**27**: 587–91.
16 Kohrt WM. Body composition by DXA: tried and true? *Med Sci Sports Exerc* 1995; **27**:1349–53.
17 Madsen KL, Adams WC, Van Loan MD. Effects of physical activity, body weight and composition, and muscular strength on bone density in young women. *Med Sci Sports Exerc* 1998;**30**:114–20.
18 Sinning WE, Wilson JR. Validity of "generalized" equations for body composition analysis in women athletes. *Res Q* 1984;**55**:153–60.
19 Going SB. Densitometry. In: Roche AF, Heymsfield SB, Lohman TG, eds. *Human body composition*. Champaign, IL: Human Kinetics, 1996:3–23.
20 Prior BM, Cureton KJ, Modlesky CM, *et al*. In vivo validation of whole body composition estimates from dual-energy X-ray absorptiometry. *J Appl Physiol* 1997;**83**:623–30.
21 Graves JE, Pollock ML, Sparling PB. Body composition of elite female distance runners. *Int J Sports Med* 1987; **8**(suppl 2):96–102.
22 Modlesky CM, Cureton KJ, Lewis RD, *et al*. Density of the fat-free mass and estimates of body composition in male weight trainers. *J Appl Physiol* 1996;**80**:2085–96.
23 Khosla S, Atkinson EJ, Riggs BL, *et al*. Relationship between body composition and bone mass in women. *J Bone Miner Res* 1996;**11**:857–63.
24 Arden NK, Spector TD. Genetic influences on muscle strength, lean body mass, and bone mineral density: a twin study. *J Bone Miner Res* 1997;**12**:2076–81.