Bone Mineral Density of Olympic-Level Female Winter Sport Athletes

NANNA L. MEYER1,2, JANET M. SHAW2, MELINDA M. MANORE3, SHAWN H. DOLAN2, ANDREW W. SUBUDHI1, BARRY B. SHULTZ2, and JAMES A. WALKER1

1The Institute for Sport Science and Medicine, The Orthopedic Specialty Hospital, Murray, UT; 2University of Utah, Department of Exercise and Sport Science, Salt Lake City, UT; and 3Oregon State University, Nutrition & Food Management Department, Corvallis, OR

ABSTRACT

MEYER, N. L., J. M. SHAW, M. M. MANORE, S. DOLAN, A. W. SUBUDHI, B. B. SHULTZ, and J. A. WALKER. Bone Mineral Density of Olympic-Level Female Winter Sport Athletes. Med. Sci. Sports Exerc., Vol. 36, No. 9, pp. 1594–1601, 2004. Purpose: To compare areal bone mineral density (aBMD) of female winter sport athletes to healthy controls of similar age and body mass index (BMI). Methods: Areal BMD (g·cm⁻²) of the whole body, lumbar spine (L2–L4), and right proximal femur were assessed by dual energy x-ray absorptiometry in athletes (N = 40; age: 26.1 ± 5.7 yr; ht: 165.6 ± 0.1 cm; wt: 63.0 ± 6.5 kg; BMI: 23.0 ± 1.9 kg·m⁻²) involved in speed skating (N = 9), snowboarding (N = 13), freestyle skiing (N = 8), bobsleigh, skeleton, luge (N = 7), and controls (N = 21; age: 26.0 ± 5.1 yr; ht: 165.0 ± 0.1 cm; wt: 62.8 ± 5.9 kg; BMI: 22.9 ± 1.3 kg·m⁻²). Results: Using independent t-tests, athletes had lower fat mass, percent body fat, and higher lean mass than controls (P < 0.001). Areal BMD was higher in athletes than controls for all skeletal sites (P ≤ 0.007). With lean tissue mass as a covariate (ANCOVA), differences in aBMD remained significant for most skeletal sites (P ≤ 0.016). Menstrual history, mean daily calcium intake, and oral contraceptive use were not associated with aBMD in the athletic group. Conclusion: Results show that female winter sport athletes have greater aBMD compared with controls of similar age and BMI. Most aBMD differences remained significant after adjusting for lean tissue mass, and athletes with a history of oligo- and/or amenorrhea had similar aBMD than their eumenorrheic counterparts. This is the first study to examine aBMD in winter sport athletes. The results support the hypothesis that the loading characteristics of intense winter sport participation have osteogenic potential. Key Words: AREAL BMD, BONE LOADING, VIBRATION LOADING, LEAN TISSUE MASS, ANCOVA, CROSS-SECTIONAL.

Several factors determine areal BMD (aBMD). Aside from genetic factors, loading from physical activity, normal menstrual function, and adequate nutrition have been associated with greater aBMD in women (18). In recent years, various sports have been used as models to identify activities that may promote bone health, with the ultimate goal of reducing the risk of osteoporosis later in life.

Mechanical loading patterns should be high in strain magnitude and rate to result in osteogenesis (15). Further, they should occur in unusual patterns and should be repeated frequently (31). Cross-sectional data have shown that athletes involved in weight-bearing activities with such loading characteristics exhibit greater aBMD compared with non-athletic controls (12,13,21–23) and athletes involved in non-weight bearing sports with a lower degree of strain magnitude and rate (13,27,28).

Winter sport activities are weight bearing and involve loading patterns that are, at least in part, characterized by high strain magnitudes and rates (3,33,35). Data on figure skaters (25) have shown that athletes have greater aBMD at loaded sites (e.g., extremities, proximal femur) compared with controls, and, in long-track speed skaters, results indicate a significant difference in aBMD at the distal femur but not at the spine in athletes compared with sedentary controls (12). In cross-country skiers, results are inconsistent with respect to aBMD, demonstrating similar or greater values in athletes compared with controls, which is probably due to the different control groups used. In the study showing similar aBMD between athletes and controls (13), a moderately active reference group, comprised of physical therapy students was used, whereas Pettersson and colleagues (21), demonstrating higher aBMD values in athletes, employed an inactive control group as comparison.

Winter sports such as snowboarding and the sliding sports (bobsleigh, skeleton, and luge) may also experi-
ference vibration loading as previously demonstrated in alpine skiing (17). Recent work on animals has shown that vibration loading, imposing low-magnitude, high-frequency mechanical signals, can increase bone formation (24). To date, only limited sport activities have been studied with respect to vibration loading (17,29), and no studies have addressed vibration loading and the potential association with aBMD in the elite sport setting. Although winter sport athletes engage in their sport on a year-round basis, off-snow or off-ice physical conditioning is an integral part of the yearly cycle. Thus, in addition to the loading patterns experienced during the execution of the winter sports, these athletes probably experience an additional benefit to the skeleton from activities that have osteogenic potential (12,13,22,27).

Lean mass is a strong predictor of aBMD in premenopausal women (16,34). Most cross-sectional studies of various sports have shown greater aBMD in female athletes along with statistically greater lean tissue mass compared with controls (21,22,27,28), although some studies did not measure (25) or report (12) lean tissue mass. Thus, it was of interest to examine whether body composition, and specifically lean tissue mass, is the primary factor explaining the higher aBMD typically seen in female athletes compared with controls. To date, only a few cross-sectional studies have addressed this question by statistically controlling for lean tissue mass (9,22). Both of these studies were conducted in adolescent female athletes.

This study examined the aBMD of elite winter sport athletes preparing for the 2002 Winter Olympics. This is the first study to investigate aBMD in Olympic-level winter sport athletes involved in biathlon, long-track speed skiing, snowboarding, freestyle skiing (aerials), and sliding sports (bobsleigh/skeleton/luge). Due to the types of mechanical forces these athletes encounter in their training, it was hypothesized that winter sport athletes have greater aBMD compared with nonathletic controls of similar age and body mass index (BMI, kg m⁻²).

METHODS

Subjects. Female athletes were recruited from international winter sport teams. All athletes were involved in international competition and were currently preparing for the 2002 Olympic Winter Games in Salt Lake City, Utah. All but two athletes were from the United States. Forty-one athletes volunteered to participate; however, one athlete was concerned about previous radiation exposure and chose not to undergo bone-scanning procedures. Therefore, 39 Caucasian and 1 African-American athlete entered the final analysis from several sports (long track speed skiing [N = 9]; freestyle skiing, aerials [N = 3]; snowboarding, alpine/ freestyle [N = 13]; biathlon [N = 8], and sliding sports [bobsleigh/skeleton/luge; N = 7]). All athletes were premenopausal. Fourteen athletes (36%) qualified to compete in the 2002 Olympic Winter Games. Four athletes won gold and one athlete won two bronze medals, whereas five athletes placed in the top 15 and another three in the top 30. Exclusion criteria for the athletic group were limited to current status of pregnancy, smoking, chronic disease, or medication known to influence bone metabolism (i.e., glucocorticoids, thyroid medication, or anabolic steroids). Athletes currently taking oral contraceptives (OC) to regulate the menstrual cycle or for birth control were not excluded.

A female control group (N = 21) was recruited from the University of Utah from a separate study conducted over the same time period, which assessed physical activity history and aBMD using the same laboratory equipment and testing personnel. This group was comprised of normally active Caucasian females who were currently involved in less than 3 h of exercise per week. Two subjects were sedentary, whereas the other subjects used jogging and walking as their most frequent, and aerobics and weight lifting as their second most frequent activity. In addition, two subjects participated in occasional winter sport activities (alpine skiing twice per month). Controls had no history of elite or collegiate sport participation; however, some subjects had participated in high school sports such as volleyball, basketball, and softball, with only a few participating in track and field, soccer, cheerleading, golf, and swimming. Seven subjects did not participate in any high school sports other than physical education classes. The following exclusion criteria applied to the control group: medication use known to alter bone metabolism including OC to regulate the menstrual cycle, history or current status of menstrual dysfunction (see definitions below), current status or history of disordered eating, cigarette smoking, BMI greater than 30 kg m⁻², current status of pregnancy, and/or clinical diagnosis of osteoporosis. Controls currently taking OC for birth control were not excluded. All participants signed a written informed consent, and all study procedures were approved by the Institutional Review Board of the University of Utah.

Questionnaires. Upon entry into the study, athletes completed questionnaires on general health, bone health, current status and history of menstrual function, OC use, and history of training. As several athletes transferred to winter sports at a later age, we created a variable, in addition to the age at training onset, to reflect more precisely the age at winter sport-specific training onset. Daily training minutes were assessed by three 24-h activity records during dry-land and on-snow/ice training. History and current status of menstrual function was assessed using standard definitions for oligo- and amenorrhea (8,19). Menstrual dysfunction (history) was defined as oligomenorrhea (three to six periods per year) (8) and amenorrhea (primary: no menses by age 16 yr; secondary: less than three periods per year) (19) during any year before this study. Menstrual dysfunction (current status) was defined as oligomenorrhea (cycle length ≥ 36 d) (8) and amenorrhea (secondary: no menses during the past three consecutive cycles) (19). As part of a different study, control participants completed the Bone Loading History Questionnaire (7) and the Paffenbiger Physical Activity Questionnaire (20). History and current status of pregnancy was obtained by questionnaire. Most subjects were scanned between days 1 and 10 of the menstrual cycle. When that was impossible, laboratory pregnancy tests (urine) were performed to rule out current status of pregnancy.
Calcium intake (dietary and supplemental) was collected in the athletic group by two 3-d weighed dietary records during dry-land and on-snow/on-ice training. Supplement use (type, brand, amount, time of ingestion) was recorded similarly to dietary intake for a given assessment period, using dietary records. Supplemental calcium intake was analyzed separately and added to the average dietary calcium intake of each individual. The Food Processor version 7.7 (ESHA, Salem, OR) was used for dietary data analysis. Labels of new foods, fortified foods, and recipes were added to the nutrient database. No differences were found for energy, macro- and micronutrient, as well as supplemental calcium intake between the two assessment periods, and thus data were pooled in order to reduce intra-individual variability. Despite known limitations (14), weighed dietary records are considered the standard method to assess dietary calcium intake (11). Due to practical constraints, calcium intake was assessed differently in athletes and controls. In the control group, calcium was assessed by a food frequency questionnaire (FFQ) (1), as this group was involved in a separate study that involved considerable additional record keeping.

**Anthropometrics and body composition.** Height and weight were measured in shorts and T-shirt without shoes, using a portable stadiometer and double-beam balance scale, respectively. Body mass index was calculated as weight (kg) divided by height squared (m²). Lean and fat tissue mass (kg) and percent body fat (% fat) were measured by dual-energy x-ray absorptiometry (DXA, Hologic QDR-1000/W, Waltham, MA). In our laboratory, the following precision errors for body composition were determined for a group of eight healthy adults who were scanned on three occasions within a period of 7 d and no more than 4 d apart: (a) lean tissue mass = 0.4%, (b) fat tissue mass = 1.3%, and (c) percent body fat = 1.3%. We asked all subjects to refrain from exercise on the day of testing and to maintain normal hydration status before testing.

**BMD.** Areal BMD (g·cm⁻²) of the whole body, lumbar spine (L2–L4), and right proximal femur was assessed by DXA. As the sports varied and not all sports could be characterized by a dominant side, the right proximal femur was used for all subjects. The following precision errors for aBMD were determined for a group of eight healthy adults who were scanned on three occasions within a period of 7 d and no more than 4 d apart: (a) lumbar spine = 1.5%, (b) total proximal femur = 1.6%, (c) femoral neck = 1.5%, (d) greater trochanter = 1.9%, and (e) whole body = 0.75%. A spine phantom of known aBMD (Hologic Corp., Waltham, MA), scanned daily throughout the course of the study (three months), indicated a long-term coefficient of variation (CV) of less than 0.5%. Monitoring these scans indicated the consistency of the machine, and no evidence for machine drift was apparent during the course of the study.

**Statistical analysis.** Group comparisons for demographic data and body composition, and aBMD of the whole body, lumbar spine, total proximal femur, femoral neck, and greater trochanter were conducted by independent t-tests. To analyze differences in aBMD independently of lean tissue mass, we conducted an ANCOVA with lean tissue mass as the covariate.

Because over 50% of athletes had either a history and/or current status of oligo- and/or amenorrhea, we further delineated the sample into athletes who had always been eumenorrheic, athletes who had either a history and/or current status of oligo and/or amenorrhea (oligo/amenorrheic athletes), and eumenorrheic controls and conducted a one-way ANOVA to compare aBMD among the three groups. Post hoc comparisons among groups were performed using the Tukey’s HSD procedures. Pearson product-moment correlation coefficients were generated to determine relationships between anthropometric (height, weight, BMI, fat tissue mass, and lean tissue mass) and dietary (calcium intake) variables and aBMD (whole body, lumbar spine, total proximal femur, femoral neck, and greater trochanter) by group and for the overall sample. To adjust for the potential effects of assessment method (FFQ and dietary records) in the association between calcium intake and aBMD, a multiple regression analysis was employed, using aBMD measures as dependent variables and calcium intake as the independent variable, after adjusting for assessment method. Due to small sample size, sport-specific results are presented as descriptive data. For aBMD comparisons, the experiment-wise error term was set at alpha = 0.10. Alpha levels were then adjusted for the number of tests according to the Bonferroni technique to control for compounding Type I error (α = 0.02). For all other statistical tests, alpha levels were set at P < 0.05. All statistical analyses were performed using SPSS statistical software package (version 11.5).

**RESULTS**

Physical characteristics of female winter sport athletes and controls are shown in Table 1. Athletes had significantly lower fat tissue mass and percent body fat and higher lean tissue mass (P < 0.001) compared with controls. In athletes, mean age at menarche was 13.4 ± 1.5 yr (range: 10–16 yr), mean age at general training onset was 10.5 ± 5.0 yr

<table>
<thead>
<tr>
<th>Variables</th>
<th>Athletes (N = 40)</th>
<th>Controls (N = 21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>26.1 ± 5.7</td>
<td>26.0 ± 5.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.0–39.0</td>
<td>190.0–34.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63.0 ± 5.5</td>
<td>62.8 ± 5.9</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>23.0 ± 1.9</td>
<td>22.9 ± 1.3</td>
</tr>
<tr>
<td>Lean tissue mass* (kg)</td>
<td>48.9 ± 4.9</td>
<td>44.4 ± 3.8</td>
</tr>
<tr>
<td>Fat tissue mass* (kg)</td>
<td>11.0 ± 2.7</td>
<td>15.7 ± 4.2</td>
</tr>
<tr>
<td>Body fat* (%)</td>
<td>17.5 ± 3.3</td>
<td>24.8 ± 4.3</td>
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*Assessed by dual energy x-ray absorptiometry.
* Comparison statistically significant between athletes and controls (P < 0.001).

Values are means and SD; range is highlighted in italics.
TABLE 2. Training history, training patterns, and daily training minutes of selected winter sports.

<table>
<thead>
<tr>
<th>Biathlon (N = 8)</th>
<th>Speed Skating (N = 10)</th>
<th>Snowboarding (N = 13)</th>
<th>Sliding Sports (N = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training history</td>
<td>Gymnastics, track and field</td>
<td>Soccer, track and field</td>
<td>Soccer, alpine skiing, tennis</td>
</tr>
<tr>
<td>Predominant training modes</td>
<td>Cycling, resistance training, roller skiing</td>
<td>Mountain biking, resistance training, snowboarding</td>
<td>Sliding on track in seated and supine positions</td>
</tr>
<tr>
<td>Daily training minutes</td>
<td>Cross-country skiing (classical and skating)</td>
<td>Speed skating (short and long track)</td>
<td>Speed skating (short and long track)</td>
</tr>
</tbody>
</table>

Daily training minutes are expressed as means and SD. 

*Assessed by 3-d 24-hr activity records during dry-land and on-snow/ice training; indicate minutes spent in activity (excluding rest periods). 

**Listed from general to specific (list is not all inclusive). 

(FIGURE 1—Areal BMD in athletes and controls. Bonferroni corrected (P < 0.02); † t-test comparisons: athletes significantly greater compared with controls (P < 0.001); ‡ ANCOVA with lean tissue mass as covariate: athletes significantly greater compared with controls (P < 0.015).

(range: 6–32 yr), and mean age at winter sport-specific training onset was 17.9 ± 5.2 yr (range: 9–33 yr). Eighteen athletes (46%) started winter sport-specific training before the age of 16 yr, whereas 21 athletes (54%) began after the age of 16 yr.

Fifty-three percent of all athletes reported having experienced either oligo- or amenorrhea at least once during their competitive career. Twelve athletes had a history of oligomenorrhea and nine athletes had a history of secondary amenorrhea. Twenty-two athletes (55%) were currently using OC. Of the 45% not currently taking OC, one was oligomenorrheic and one amenorrheic. Three athletes and three controls were parous. Nine control participants (44%) were current OC users.

All but five athletes were involved in organized team practice. All athletes were training in pursuit of qualifying for the 2002 Winter Olympics. Table 2 displays training history, predominant training modes, and daily training minutes by sport during dry-land and on-snow/ice training.

Areal BMD was significantly higher in athletes compared with controls for the whole body (1.144 ± 0.061 g·cm⁻² vs 1.081 ± 0.072 g·cm⁻²; P = 0.001), lumbar spine (1.160 ± 0.103 g·cm⁻² vs 1.078 ± 0.082 g·cm⁻²; P = 0.003), total proximal femur (1.035 ± 0.106 g·cm⁻² vs 0.928 ± 0.108 g·cm⁻²; P < 0.0001), femoral neck (0.946 ± 0.108 g·cm⁻² vs 0.862 ± 0.124 g·cm⁻²; P = 0.009), and greater trochanter (0.814 ± 0.091 g·cm⁻² vs 0.717 ± 0.092 g·cm⁻²; P < 0.0001) (Fig. 1). Percent difference in aBMD for athletes ranged from 5.8% (whole body) to 13.5% (greater trochanter) above control values. When lean tissue mass was used as a covariate, aBMD remained statistically different between athletes and controls for whole body (P = 0.01), total proximal femur (P = 0.013), and greater trochanter (P = 0.005).

One-way ANOVA between eumenorrheic athletes (N = 19), oligo/amenorrheic athletes (N = 21), and eumenorrheic controls (N = 21) is shown in Figure 2. Eumenorrheic athletes had significantly greater aBMD at all sites compared with eumenorrheic controls, except for the femoral neck, which with
aP value equal to 0.02, was not considered statistically significant. Oligo/amenorrheic athletes had significantly higher aBMD for the total proximal femur (P < 0.004) and greater trochanter (P < 0.0001) compared with eumenorrheic controls. There were no statistically significant differences between oligo/amenorrheic and eumenorrheic athletes at any skeletal site. Lean tissue mass was significantly greater in eumenorrheic athletes compared with eumenorrheic controls (51.2 ± 7.5 kg vs 44.4 ± 3.8 kg; P = 0.001), whereas there were no significant differences in lean tissue mass between oligo/amenorrheic athletes and eumenorrheic controls and oligo/amenorrheic and eumenorrheic athletes.

Oral contraceptive use may have influenced our results due to the high prevalence in both athletes and controls. Because the number of athletes without menstrual dysfunction and OC use was too small, aBMD comparisons were repeated between all athletes (N = 40) and those controls who did not use OC (N = 13). Results remained similar with athletes having higher aBMD at the whole body (P = 0.018), total proximal femur (P = 0.007), and greater trochanter (P = 0.004), with a tendency for lumbar spine (P = 0.062) and femoral neck (P = 0.049). When lean tissue mass was used as a covariate, the difference between oligo/amenorrheic athletes and eumenorrheic controls and oligo/amenorrheic and eumenorrheic athletes remained statistically significant (P < 0.027).

In athletes, lean tissue mass was significantly correlated with whole body (r = 0.402; P = 0.01) and lumbar spine (r = 0.493; P = 0.001) and lumbar spine (r = 0.493; P = 0.001) but not with total proximal femur, femoral neck, and greater trochanter (r = 0.148 to 0.277) aBMD. In controls, lean tissue mass was significantly correlated with total proximal femur (r = 0.460; P = 0.036) and greater trochanter (r = 0.540; P = 0.012) but not with whole body, lumbar spine, and femoral neck (r = 0.060 to 0.325) aBMD. Fat tissue mass was not significantly correlated with aBMD at any skeletal site in either group. Considering all subjects, weight and BMI were significantly correlated with whole body and lumbar spine aBMD, height with lumbar spine aBMD, and lean tissue mass with aBMD of all skeletal sites (Table 3). Calcium intake was not associated with any aBMD site in either group and in the overall sample, before and after adjusting for dietary assessment method.

Sport-specific results are presented in Table 4. All sports had similar age at menarche and age at general training onset. Age at winter sport-specific onset was highest in sliding sport athletes (23.0 ± 11.6 yr) and lowest in speed skaters (15.3 ± 2.2 yr). Speed skaters also demonstrated the greatest number of years on the team compared with the other sports (7.3 ± 3.5 yr). Lean tissue mass was highest in speed skaters and percent body fat lowest in speed skaters and biathletes. Speed skaters and sliding sport athletes had the highest aBMD at the lumbar spine, total proximal femur, femoral neck, and greater trochanter, whereas whole body aBMD was highest in sliding sport athletes.

FIGURE 2—Areal BMD in eumenorrheic athletes, oligo/amenorrheic athletes, and eumenorrheic controls; † ANOVA with post hoc comparisons: athletes significantly greater compared with controls (P < 0.01).

DISCUSSION

In the current cross-sectional study, the aBMD of female athletes involved in selected winter sports during the preparation for the 2002 Olympic Winter Games was evaluated and compared with the aBMD of normally active controls of similar age and BMI. Collectively, it was found that winter sport athletes had significantly greater whole body, lumbar spine, total proximal femur, femoral neck, and greater trochanter aBMD compared with controls. Furthermore, the difference for the whole body, total proximal femur, and particularly the greater trochanter, remained statistically significant when lean tissue mass was used as a covariate.

This study was unique in that it addressed aBMD among a group of athletes who, to date, has received only limited attention in the literature. Further, nonathletic controls were of similar age and BMI as the winter sport athletes, which made it possible to control for these two factors, which have previously been shown to strongly predict aBMD (10,26). Furthermore, this study was one of the few cross-sectional studies to statistically control for the relative influence of lean tissue mass on aBMD.

Winter sports are characterized by highly variable training modes that span a wide spectrum of strain magnitudes and rates, considered necessary for osteogenesis (3,4,17,33). The sports assessed in this study included freestyle skiing, snowboarding, long track speed skating, bobsleigh, skeleton, and luge, and biathlon, a combination of cross-country skiing and shooting. Although little attention has been given to these athletes in the realm of bone health, information related to the nature of each sport provides insight into how bone may be influenced by participation.

Of the sports studied, freestyle skiing and snowboarding are most characterized by high strain magnitude and rate. Training for freestyle skiing, specifically the aerial discipline, is very similar to training for gymnastics, and many freestyle skiers have a gymnastics background. Previous research on female adult gymnasts has established that this sport has a high osteogenic potential (23,27,28). Snowboarders using the halfpipe experience a large jumping component, whereas their alpine counterparts participate in...
activities similar to those of alpine skiers (around gates), with the addition of jumping over and around obstacles at high speeds (snowboard cross). Impact loads while landing from jumps may explain the high rates of ankle fractures experienced in snowboarders (35). Due to the lack of data on regional forces in snowboarders, it may be possible to extrapolate from data on alpine skiers, who experience forces of 9 to 13 times body weight at the level of the hip (33).

A large 19% difference in trochanteric aBMD was found between speed skaters and controls. Ground reaction forces in speed skating are relatively low, about 1.5 times body weight (2). However, maximal moment values at the hip and knee are high and reach values of 140–160 Nm during skating in the straight part of the track (3), with greater values expected when skating the turns. We did not measure side-to-side hip aBMD differences, but higher loads are applied to the left leg during speed skating the turns than to the right leg (4), given that speed skating is done in the counter-clockwise direction.

Recent animal studies have shown that high strain rates at lower magnitudes are also effective in stimulating bone formation. Data by Rubin et al. (24) suggest that frequencies of >20 Hz can increase bone formation. Vibration forces are probably experienced by all of the sports we studied. Frequencies of up to 30 Hz have been measured at the hip in alpine skiers by Mester et al. (17), with ground reaction forces of up to nine times body weight, encountered in brief periods or impacts during a turn. It is likely that alpine snowboarders experience similar vibrations as documented in alpine skiers. The sliding sports (bobsleigh, skeleton, and luge) travel down a prepared run made of ice at 80–120 mph. Vibration loading in these sports, which has not been measured, may be particularly high, with an unusual loading distribution due to the seated and supine body positioning. In the current study, the sliding sport athletes had the highest whole body aBMD of all sports. Vibration loading in the supine or seated position may be systemic in nature, possibly affecting the entire skeleton. Further, skeletal muscle action may not be able to effectively attenuate impacts when in a seated or supine compared with a standing position (6).

Whether vibration loading affects aBMD in humans has recently been assessed using an 8-month, whole body vibration protocol. The training program had no effect on bone parameters and showed only a slight change in strength (+3.7%), despite a significant increase in vertical jump performance in young, healthy males and females (30). In another study, a 12-wk training program using a vibration protocol with gradual progression demonstrated significant strength gains (16.6%), which were comparable to those elicited by a resistance-training program in untrained young females (5). Unfortunately, aBMD was not assessed. Further research should test the hypothesis of whether vibration loads of the magnitude and frequency experienced in competitive sports have the potential to increase aBMD, and whether this effect is related to strength and lean tissue mass.

All of the athletes studied participated in considerable dry-land training (Table 2). Cycling, running, and track and field as well as resistance and plyometric training are common among these athletes. In addition, specific activities such as roller skiing, in-line skating, and skate boarding may impart vibration forces (29), posing the question of whether the winter sport per se or the dry-land training is more osteogenic in these athletes. Technological advances make it possible for many winter sport athletes, including those in the present sample, to participate in winter sport-specific training year-around, with a yearly average of 180–200 days spent on snow/ice. Nevertheless, we cannot rule out that

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**TABLE 3. Pearson product-moment correlations for body composition and areal bone mineral density measures in all subjects.**

<table>
<thead>
<tr>
<th></th>
<th>Whole Body</th>
<th>Lumbar Spine</th>
<th>Total Proximal Femur</th>
<th>Femoral Neck</th>
<th>Greater Trochanter</th>
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</thead>
<tbody>
<tr>
<td><strong>Values represent correlation coefficients.</strong></td>
<td></td>
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<tr>
<td><strong>Assessed by dual energy x-ray absorptiometry.</strong></td>
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<tr>
<td><strong>Correlation significant at 0.001 level.</strong></td>
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<tr>
<td><strong>Correlation significant at 0.01 level.</strong></td>
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<tr>
<td><strong>Correlation significant at 0.05 level.</strong></td>
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**TABLE 4. Body composition and areal bone mineral density by sport in winter sport athletes (N = 40).**

<table>
<thead>
<tr>
<th></th>
<th>Biathlon (N = 8)</th>
<th>Speed Skating (N = 9)</th>
<th>Snowboarding (N = 13)</th>
<th>Freestyle Skiing (N = 3)</th>
<th>Sliding Sports (N = 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean tissue mass* (kg)</td>
<td>48.4 ± 4.1</td>
<td>50.4 ± 4.1</td>
<td>49.2 ± 4.2</td>
<td>43.7 ± 5.2</td>
<td>49.2 ± 7.7</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>15.8 ± 2.6</td>
<td>15.4 ± 3.1</td>
<td>19.8 ± 3.1</td>
<td>18.3 ± 2.9</td>
<td>17.4 ± 2.2</td>
</tr>
<tr>
<td>Whole body (g·cm(^{-2}))</td>
<td>1.135 ± 0.036</td>
<td>1.158 ± 0.060</td>
<td>1.127 ± 0.045</td>
<td>1.123 ± 0.041</td>
<td>1.181 ± 0.112</td>
</tr>
<tr>
<td>Lumbar spine* (g·cm(^{-2}))</td>
<td>1.114 ± 0.094</td>
<td>1.196 ± 0.064</td>
<td>1.141 ± 0.110</td>
<td>1.188 ± 0.072</td>
<td>1.196 ± 0.150</td>
</tr>
<tr>
<td>Total proximal femur* (g·cm(^{-2}))</td>
<td>1.007 ± 0.074</td>
<td>1.086 ± 0.126</td>
<td>1.017 ± 0.090</td>
<td>0.989 ± 0.028</td>
<td>1.058 ± 0.156</td>
</tr>
<tr>
<td>Femoral neck* (g·cm(^{-2}))</td>
<td>0.890 ± 0.043</td>
<td>0.992 ± 0.106</td>
<td>0.931 ± 0.102</td>
<td>0.953 ± 0.026</td>
<td>0.980 ± 0.179</td>
</tr>
<tr>
<td>Greater trochanter* (g·cm(^{-2}))</td>
<td>0.790 ± 0.062</td>
<td>0.854 ± 0.113</td>
<td>0.797 ± 0.082</td>
<td>0.818 ± 0.030</td>
<td>0.825 ± 0.124</td>
</tr>
</tbody>
</table>

Values are means and standard deviations.

**BONE MINERAL DENSITY OF FEMALE WINTER SPORT ATHLETES**

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dry-land training and the involvement in sports before the onset of winter sports partially contributed to our results. A longitudinal design, following young winter sport athletes in comparison to their summer sport counterparts and controls may be necessary to answer this question.

Lean tissue mass was a significant correlate of aBMD in the present study, which is in agreement with previous data (16,34). However, lean tissue mass was correlated with aBMD somewhat differently for the athletic and control groups. Differences in sample size and in the degree of variability (in lean and bone measures at specific skeletal sites) between the two groups may have contributed to the heterogeneity in these associations. For example, the range of lean tissue mass was twice as high in the athletic group (33.1 kg) compared with the control group (14.7 kg). Combining the two groups (N = 61) elicited significant correlations between lean tissue mass and all aBMD sites. In the study by Madsen et al. (16), no significant correlations were found between lean tissue mass and aBMD in young sedentary women. However, the inclusion of 20 athletes involved in weight bearing sports in the analysis with the sedentary subjects (N = 60) led to significant findings with similar correlation coefficients (r = 0.43–0.45; P < 0.001) as were found in the current study (r = 0.37–0.50; P < 0.001). In the present study, lean tissue mass was used as a covariate based on the significant correlations with aBMD at all skeletal sites for the entire sample, current data identifying lean tissue mass as strong predictor of aBMD (16,34), and the significantly higher lean tissue mass in athletes compared with controls found in this (P < 0.0001) and several other studies (21–23,28). Adjustments for lean tissue mass may be necessary in order to decipher whether the activity per se is associated with greater aBMD or whether lean mass mediates the relationship between the activity and aBMD.

Although several cross-sectional studies, involving a variety of sports, have adjusted for body mass and/or bone size (12,23,28), only a few studies have controlled for the influence of lean tissue mass on aBMD. Pettersson et al. (22) compared young female rope skippers, soccer players, and controls. Soccer players had higher lean tissue mass compared with rope skippers and controls. Initial data showed greater aBMD in both rope skippers and soccer players compared with controls for the whole body, lumbar spine, and total proximal femur. Adjusting for lean tissue mass using ANCOVA showed that soccer players no longer had higher aBMD compared with controls, and aBMD remained higher for rope skippers only for the whole body and lumbar spine but not the proximal femur compared with controls. These data confirm that lean tissue mass contributes to the variance in aBMD. However, the influence of lean tissue mass on aBMD appears to be specific to weight-bearing sports (9,27), which should be taken into consideration.

Lower bone mass is often but not always found in athletes compared with those who had never experienced menstrual dysfunction and controls. Previous data on gymnasts (23) and figure skaters (25) have found similar results. It is likely that the early involvement in sports before menarche in oligo/amenorrheic compared with eumenorrheic athletes (9.0 ± 2.2 yr vs 12.1 ± 6.6 yr; P = 0.052), the slightly earlier onset of winter sport-specific training (17.9 ± 4.3 yr vs 19.5 ± 6.6 yr; P = 0.058), and the related loading characteristics experienced in winter sports may, at least in part, explain these results.

This study has limitations. Areal BMD does not assess the depth of the skeletal site due to its two-dimensional nature and, therefore, is a limited measure of true volumetric density. Self-selection bias in cross-sectional studies is always a concern, particularly when athletes are compared with their less-active counterparts. The winter sport athletes in this study may have genetically higher aBMD that contributes to success in their respective sports. In addition, the small sample size within each sport and the lack of quantitative measures of the loading characteristics of each sport limited the ability to address aBMD differences among sports. Selecting controls of similar age and BMI and controlling for lean tissue mass helps support that aBMD differences were, at least in part, associated with mechanical loading. The fact that several athletes and controls were using OC and that athletes had a variety of current and historical menstrual disturbances presents a concern, although a statistical check of aBMD among various subgroups confirmed the primary results. Lastly, calcium intake was assessed by different assessment methods in the athletes and controls, which is a limitation. Nevertheless, the FFQ used in this study has been shown to correlate relatively well with daily calcium intake when compared with a 7-d food record (1). Further, we addressed this issue by statistically adjusting the relevant associations (i.e., between calcium intake and aBMD for the whole sample) for dietary assessment method, which did not change the within-group nonsignificant results. Still, calcium intake could account for the aBMD differences we observed, as the athletes may have benefited from higher calcium intake over a longer period of time. However, we are unable to address this issue with our data. In general, lifetime calcium intake is a better predictor of aBMD than acute dietary calcium intake (32) reported from either dietary records or the FFQ used in this study.

In conclusion, this study shows that certain winter sports are associated with greater aBMD, particularly at the proximal femur and independently of lean tissue mass, despite a high prevalence of menstrual dysfunction. Early exposure to various sports and mechanical loading across a wide spectrum of strain magnitudes and rates applied in unusual patterns as experienced in winter sport athletes may explain the greater aBMD found in athletes compared with controls. This is the first study to compare aBMD in winter sport athletes and controls. Studies are needed to characterize mechanical loading patterns of winter sports to better describe their osteogenic potential.
effectually on a longitudinal basis. Future research should also test the hypothesis whether regular exposure to vibration, in addition to the ground reaction forces and skeletal muscle action experienced in winter sports, leads to positive changes in aBMD.

REFERENCES