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Original Article

Alpine skiing is associated with higher femoral neck bone mineral density

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Abstract

Objective: To evaluate the influence of elite-level alpine skiing on athletes' skeleton. **Methods:** Thirteen professional alpine skiers (9 males and 4 females with mean age of 22.6 years) and their age- and height matched control subjects were measured with dual energy X-ray absorptiometry (total body, lumbar spine, proximal femur, forearm) and quantitative ultrasound (hand). **Results:** After adjusting for sex, age, weight and height, between-group differences were 15% (p=0.012) for the lumbar spine, 14% (p=0.022) for the femoral neck, 10% (p=0.051) for the total hip, and 11% (p=0.001) for the total body favoring the alpine skiers. However, after controlling for total body lean mass (~muscle mass), the group-differences lost their statistical significance, the borderline 10% difference (p=0.051) in femoral neck BMD excluded. **Conclusion:** Factors contributing to the alpine skiers' higher BMD may not only include the greater muscle mass (~stronger muscles) of these athletes but also a large number of impacts and possibly other high-frequency features in external loading generated by the high-speed skiing performance.

Keywords: Bone, Dual X-ray Absorptiometry, Exercise Loading, Muscle Mass, Quantitative Ultrasound

Introduction

Athletes provide unique opportunities to study long-term influences of exercise loading on bone. Sports activities require specific muscle activity, and basically all controlled body movements are generated by coordinated contractions of skeletal muscles, which, in turn, provide the fundamental source of skeletal loading[1]. Bone structure and geometry adapt to habitual loading in a site-specific and functionally meaningful fashion; ie, only sufficiently loaded bones are strengthened[2].

During locomotion and other movements, incident muscle forces are often higher compared with simultaneous ground reaction forces because the tendons of muscles are generally attached close to the joints they move making the respective lever arms mechanically disadvantageous[3]. Besides incident muscle forces, external ground reaction force patterns may contribute to the skeletal response. Sports involving high ground impacts irrespective of their direction are generally associated with a strong phenotype of weight-bearing skeleton, including the clinically important proximal femur[4-6]. In contrast, the power lifting involving extreme muscle forces produced at low speed is not particularly associated with a stronger proximal femur[6].

Alpine skiing – a highly dynamic athletic performance which is mainly done in a squating body position and which comprises coordinated turns and fast reactions to cope with quickly changing loading and circumstances – provides a pertinent model to evaluate specific influence of such a loading on bone. At the elite level this sport is performed at high speed and it requires both high muscle strength and power while the rough and bumby surface creates haphazard forces to the body through the feet. So far only two studies of adult elite alpine skiers, one of six Finnish men and the other of 24 Canadian

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men and women, have been published[7,8]. In the recent study of Schipilow et al. using high-resolution peripheral computed tomography (HR-pQCT) over 20% higher trabecular density was observed both at distal radius and tibia among alpine skiers, in addition to larger bone cross-sections[8]. Similarly in the DXA and pQCT study of Nikander et al, almost 20% higher areal bone mineral density (BMD) at the lumbar spine and femoral neck were observed, and the pQCT-measured cortical bone at the distal tibia of alpine skiers was about 80% thicker compared with physically active but nonathletic young men[7]. Interestingly this difference exceeded the mean 60% benefit observed in the triple jumpers' distal tibia in a similar comparison[4]. Maximal reaction forces in the triple jump performance can be up to 20 times body weight on one leg[4], whereas in alpine skiing these forces are typically 2-5 times of body weight and depend on skier's level, skiing mode and slope steepness[7,9,10]. One can thus speculate on that these contrasting findings in the load magnitude imply a specific nature for skeletal loading occurring during alpine skiing. The goal of the present study was to elaborate the influence of alpine skiing on athletes' skeleton.

Materials and methods

Subjects

In the present cross-sectional study, the study group comprised 4 female and 9 male alpine skiers (mean age 22.6, SD 1.4 years) with a training history of 12.5 (SD 3.6) years. Their mean weekly training time was 19.6 (SD 8.8) hours. All skiers were members of Polish Olympic, National or University teams. The criteria for inclusion were professional ski training for at least 5 years and written informed consent both from the athlete and his/her coach. The control group comprised a convenience sample of healthy age- and sex-matched students (n=13: 4 females and 9 males) recruited from Medical University of Silesia, Katowice, Poland. Exclusion criteria in both groups were a recent fracture, presence of thyroid, intestine, kidney or endocrine system disease(s), or current or past use of medication known to influence bone metabolism (corticosteroids, antidepressants, anticonvulsants and anticoagulants). At the time of the study, all female subjects had regular menstrual cycles during the past year (women were considered eumenorrheic if they had 10-12 spontaneous menses during last 12 months). The study was approved by the Medical University of Silesia Ethics Committee and each subject gave a written informed consent.

Methods

The measurements were performed within about 2 weeks after the end of the competition season (season lasts from October to April). All measurements of one person were performed on the same day.

Dual-energy X-ray absorptiometry (DXA) measurements were performed using Hologic Explorer (Hologic Inc., Waltham, MA, USA; software version: 13.0:3). Bone mineral density (areal BMD, g/cm^2) of lumbar spine (L1-L4), left femoral neck and total hip, distal and shaft regions of radius as well as total body BMD (without head) were measured. In addition, fat-% and total body lean mass were obtained from the total body scan. Based on repeated measurements of 25 adults, the precision (CV%rms) of DXA measurements ranged from 1.5% to 2.3%. All measurements were performed by one operator.

Skeletal status was also assessed with quantitative ultrasound device (QUS, DBM Sonic 1200, IGEA, Italy) which measures amplitude-dependent speed of sound (Ad-SoS, m/s) at distal epiphyses of non-dominant hand phalanges II trough V. The test result was an average of four measurements. The precision (CV%rms) of QUS measurements was 0.6% based on repeated measurements of 15 adults. All measurements were performed by one operator.

Height and weight were measured with bare feet and in underwear using standard laboratory stadiometer and weight scale. All subjects completed a questionnaire about a medical history and use of medications. Study personnel checked completeness and accuracy of the questionnaire.

Statistical analysis

Statistical analyses were done with SPPS 21.0 (SPSS Inc., Chicago, IL, USA). Means and standard deviation (SD) are given as descriptive statistics. Between-group differences in bone traits were first assessed by analysis of variance (ANOVA) and then estimated by analysis of covariance (ANCOVA) using sex, age, weight and height as pre-planned common covariates (model 1), and when the observed difference was significant, total body lean mass was also used as a covariate (model 2). Lean mass was considered as a proxy for dynamic muscle force and power[11]. A p-value of less than or equal to 0.05 was considered statistically significant.

Results

Mean group characteristics of the alpine skiers and their control subjects broken down by sex are shown in Table 1. Body weight and lean body mass were 11.5 % and 16.6 % higher on average among the alpine skiers compared to their controls (men and women combined), respectively, but these differences did not reach significance. Body fat-% was significantly 17.5% lower among the skiers ($p<0.05$).

According to ANOVA, all but forearm bone values differed significantly between the groups. Alpine skiers' mean lumbar spine BMD was 19% ($p=0.001$), femoral neck BMD 19% ($p=0.003$), total femur BMD 16% ($p=0.005$), and total body BMD 15% ($p<0.001$) higher compared with the control group.

Table 2 shows the sex-, age-, height- and weight-adjusted between-group differences in all bone traits. According to ANCOVA (model 1), alpine skiers' lumbar spine, femoral neck, and total body BMD differed significantly from the control group values, whereas the radial BMD did not differ either at distal or shaft site. There was a borderline trend for a small 2% difference in the hand Ad-SOS value ($p=0.071$) and 10% difference for the total femur BMD ($p=0.051$). The magnitudes

	Alpine skiers		Controls	
	Males	**Females**	**Males**	**Females**
N	9	4	9	4
Age (years)	22.9 (1.4)	22.0 (1.4)	22.9 (1.4)	22.0 (1.4)
Height (m)	1.82 (0.08)	1.69 (0.08)	1.82 (0.08)	1.65 (0.04)
Weight (kg)	82.6 (11.8)	66.3 (6.7)	76.8 (13.0)	53.3 (3.5)
Lean mass (kg)	64.2 (9.6)	47.4 (3.4)	56.5 (6.7)	37.4 (5.9)
Fat-%	19.9 (2.7)	25.7 (4.1)	25.7 (6.4)	27.8 (4.6
Phalangeal Ad-SOS (m/s)	2153 (54)	2155 (41)	2140 (35)	2096 (78)
Distal radius BMD (g/cm²)	0.418 (0.125)	0.458 (0.023)	0.416 (0.136)	0.314 (0.128)
Radial shaft BMD (g/cm²)	0.696 (0.102)	0.808 (0.101)	0.755 (0.099)	0.650 (0.073)
Lumbar spine BMD (g/cm²)	1.167 (0.134)	1.202 (0.101)	0.970 (0.121)	1.031 (0.168)
Femoral neck BMD (g/cm²)	1.125 (0.090)	1.018 (0.099)	0.928 (0.123)	0.897 (0.233)
Total femur BMD (g/cm²)	1.164 (0.048)	1.091 (0.122)	0.996 (0.137)	0.959 (0.239)
Total body BMD (g/cm²)	1.080 (0.061)	0.991 (0.051)	0.939 (0.086)	0.860 (0.107)

Table 1. Clinical and bone characteristics of alpine skiers and their sex- and age-matched control subjects (mean, SD).

Bone trait	Alpine skiers	Controls	95% CI[a]	95% CI[b]
Phalangeal Ad-SOS (m/s)	2155 (49)	2127 (53)	-4 – 88	ND
Distal radius BMD (g/cm²)	0.430 (0.105)	0.384 (0.137)	-0.095 – 0.127	ND
Radial shaft BMD (g/cm²)	0.730 (0.111)	0.723 (0.096)	-0.099 – 0.105	ND
Lumbar spine BMD (g/cm²)	1.178 (0.121)	0.989 (0.133)	**0.037 – 0.262**	-0.054 – 0.241
Femoral neck BMD (g/cm²)	1.092 (0.103)	0.919 (0.154)	**0.021 – 0.242**	-0.005 – 0.295
Total femur BMD (g/cm²)	1.142 (0.080)	0.985 (0.165)	-0.001 – 0.204	ND
Total body BMD (g/cm²)	1.053 (0.071)	0.915 (0.096)	**0.043 – 0.156**	-0.018 – 0.116

[a] in the model 1, sex, age, weight and height were used as pre-planned covariates; [b] in the model 2, total body lean mass was used as an additional covariate; ND, model 2 was not determined if model 1 did not reach significance.

Table 2. Bone traits (mean, SD) and adjusted group-differences (95% confidence interval) between the pooled (men and women together) alpine skier and control groups.

of statistically significant between-group differences were 15% (p=0.012) for the lumbar spine, 14% (p=0.022) for the femoral neck, and 11% (p=0.001) and for the total body favoring the alpine skiers. However, when the total body lean (~muscle) mass was taken into account (model 2), all group-differences lost statistical significance. The adjusted 10% difference in the mean femoral neck BMD showed yet borderline significance (p=0.051).

Discussion

The present bone results from 13 adult Polish professional alpine skiers concur with respective findings in six Finnish and 24 Canadian alpine skiers[7,8], and also with the common notion that the loading caused by various weight-bearing athletic performances confers clear skeletal benefits over a wide age range, and that these benefits are more distinct when high peak forces (impacts) are involved[6,12-15]. In the non-weight-bearing upper extremities, no significant between-group influence was seen, the borderline slight influence on the phalanges excluded.

Alpine skiing at the elite level is a very demanding sports event that requires much from athlete's reactions, physical capacity, endurance and technique for a successful performance[16]. Whereas the link between dynamic muscle forces and bone traits is well established[1,2], there may be some other loading related factors in alpine skiing than sole incident muscle forces that modulate these athletes' skeletal adaptation. For example, very short, but high external force peaks induced by the uneven track surface are transmitted to the lower extremities, let alone the high number of such impacts during typical training sessions. The bumpy and curved skiing track along the slope with varying steepness results in a spectrum of external forces that can vary a lot in terms of magnitude, frequency and number as a function of skiing speed. The faster the speed, the higher the magnitude and the higher the frequency content of loading. For illustration, this can be seen from hip-level accelerations recorded from two differently performing recreational skiers (Figure 1). Both in training and competition elite alpine skiers' speed is much higher than in

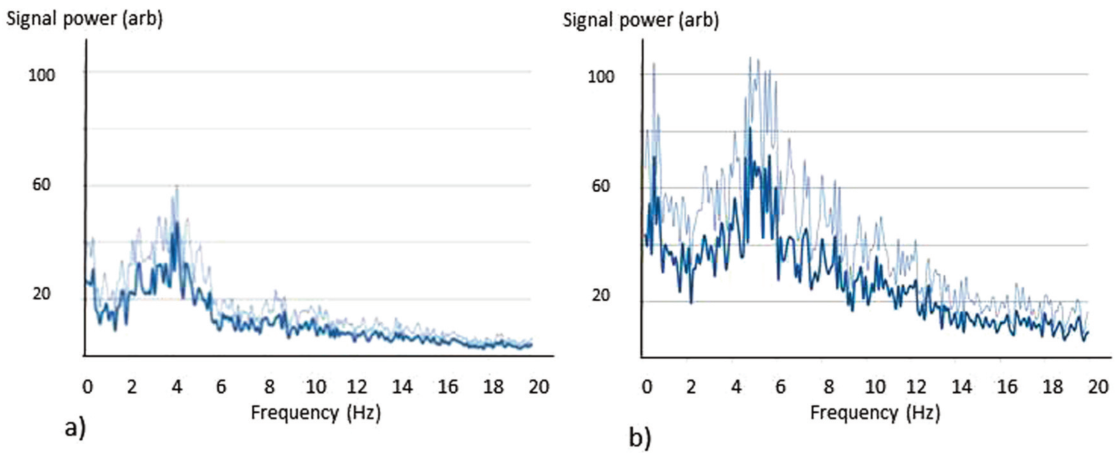

Figure 1. Frequency spectra of hip-level accelerations measured with accelerometry[26] from two differently performing recreational skiers during four successive different skiing performances. The two curves describe the range of loading power (in arbitrary values) within the frequency range from 0 to 20 Hz determined by Fast Fourier Transformation: a) a skier with a slow speed and the b) a skier with a faster speed. The influence of speed on both the loading magnitude and its frequency content is evident.

recreational skiers. For example, at the competition speed of 30 m/s, even low-height bumps about one meter apart would generate substantial vibration loading at about 30 Hz. Obviously, the loading pattern is modulated to some extent not only by the skiing surface but also the skier's body biomechanics, technique and skills[10]. It is known that elite alpine skiing can modulate bone turnover which is necessary for bone adaptation[17]. It is also known that short-term (some minutes, comparable to a typical competition performance) whole body vibration training can confer various effects on human body and physiology, including slightly increased BMD[18]. Thus, high-frequency and high-magnitude vibratory nature of elite alpine skiing together with vigorous eccentric and concentric muscle activity may account for the skiers' high BMD, at least to some extent.

It is, however, recalled that bone adaptation is related to the combination of load magnitude and number of loads[19]. Therefore, the observed osteogenic potential of alpine skiing may simply be a result of a large number of impacts - not a result of vibratory stimulus *per se*. For comparison, sprinters experience a large number of peak ground reaction forces of 4-5 times body mass, similar to the values proposed in downhill skiing[7,9,10], but much lower than those in triple jumpers[4] - yet sprinters have a similar bone strength advantage compared to controls as triple jumpers[20]. Alpine skiing may just denote one form of moderate to high impact sport.

The present study has several limitations which need to be discussed. First, the cross-sectional nature of the study impeded obtaining proof for cause-effect relationship between alpine skiing and bone traits. Second, selection bias is always a challenge in cross-sectional studies of elite athletes - physically stronger people with inherently stronger bones are more likely to start sports that require high muscle performance and certain body type. However, be it noted that particularly among the men (but not among women) the bone traits in the non-weight bearing bones were similar suggesting no pre-existing difference (Table 1), while in the weight-bearing lower extremity bones, both previous studies and the present study of adult alpine skiers indicate consistent osteogenic influence of alpine skiing[7,8], supported by observations in adolescent alpine skiers as well[21,22]. Third, the contribution of supplementary training to bone traits (i.e., that of endurance training (running) and resistance training), could not be assessed because such an information was not collected from the athletes. Fourth, the sample size was small, which made the study underpowered to detect significant group-differences with a more complicated analysis (ANCOVA). Particularly the small sample of women prevented from detecting potential differences between sexes (Table 1). The non-significant trend of higher BMD in women mirrors previous observations of female athletes[20]. It is possible that because of the generally lower level of habitual vigorous physical activity in females[23] the high-level sport represents a greater departure from normal loading and may thus be a greater stimulus. Fifth, the relevance of some covariates used in the present study may be questioned. In particular, the lean mass is only a proxy of muscle force and does not cover all relevant aspects of loading caused by muscle activity; two thirds of dynamic muscle performance remains unexplained[11]. Therefore, more specific data on physical performance, dynamic muscle force and power as well as acceleration data from actual professional alpine skiing performance would have been useful. Fifth, while the present bone measurements were obtained from the clinically relevant lumbar spine and proximal femur with DXA in addition to forearm and hand measurements, it would have been interesting to obtain more detailed information on bone structure and geometry, especially at the directly loaded distal tibia and also proximal femur. The strengths of the present study include the assessment of bones from both the weight-bearing and non-weight-bearing skeleton, and the body composition assessment with DXA.

The present ~15% group-differences in the mean lumbar spine and femoral neck BMD values, together with similar findings in Finnish alpine skiers[7], correspond to more than one T-score which can be considered clinically meaningful in terms of reduced risk of future fragility fractures. Obviously, alpine skiing cannot be a panacea for general improvement in bone health because of high risk of serious injuries[24]. Nevertheless, recreational alpine skiing is quite popular from children up to older adults worldwide, and this type of exercise may well contribute to better muscle performance, dynamic balance and reactions in these individuals. Thus, through improved physical functioning recreational alpine skiing may also be of some relevance in terms of falls prevention and related fractures in later life. When started in adolescence, a solid ground for lower risk of fragility fractures can be built in the form of better motor skills, stronger muscles and higher BMD[21,22]. Optimal influence on bone health with exercise training can be obtained particularly during the growth spurt of adolescence[25].

In conclusion, alpine skiing was significantly associated with higher BMD compared to sex-and age-matched controls. Factors contributing to the alpine skiers' higher BMD may not only include the greater muscle mass (~stronger muscles) of these athletes but also a large number of impacts and possibly other high-frequency features in external loading generated by the high-speed skiing performance. Further specific studies are needed to characterize the potentially high osteogenic nature of alpine skiing.

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