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. Bone structure and geometry adapt to habitual loading in a site-specific and functionally meaningful fashion; ie, only sufficiently loaded bones are strengthened.

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. 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. In contrast, the power lifting involving extreme muscle forces produced at low speed is not particularly associated with a stronger proximal femur.

Alpine skiing – a highly dynamic athletic performance which is mainly done in a squatting 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 bumpy 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
men and women, have been published. 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. 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 cor-
tical bone at the distal tibia of alpine skiers was about 80%
higher with physically active but nonathletic young men.
Interestingly this difference exceeded the mean 60% benefit observed in
the triple jumpers’ distal tibia in a similar comparison. Maximal reaction forces in the triple jump per-
formance can be up to 20 times body weight on one leg, 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. One can thus speculate on that these con-
trasting 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 com-
prised 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 con-
venience 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 (corticos-
teroids, antidepressants, anticonvulsants and anticoagulants).
At the time of the study, all female subjects had regular men-
strual cycles during the past year (women were considered eu-
menorrheic 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 writ-
ten informed consent.

**Methods**

The measurements were performed within about 2 weeks
after the end of the competition season (season lasts from Oc-
tober to April). All measurements of one person were per-
formed 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
(area BMD, g/cm²) 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 ultra-
sound 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 under-
wear using standard laboratory stadiometer and weight
scale. All subjects completed a questionnaire about a medical
history and use of medications. Study personnel checked com-
pleteness 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 (AN-
COVA) using sex, age, weight and height as pre-planned com-
mon covariates (model 1), and when the observed difference
was significant, total body lean mass was also used as a co-
variate (model 2). Lean mass was considered as a proxy for
dynamic muscle force and power. 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 signif-
icantly 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 AN-
COVA (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% dif-
fERENCE for the total femur BMD (p=0.051). The magnitudes
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) for the total body favor-
ing 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% dif-
ference 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 skiers7,8, and also with the common notion
that the loading caused by various weight-bearing athletic per-
formances confers clear skeletal benefits over a wide age range,
and that these benefits are more distinct when high peak forces
(impacts) are involved6,12-15. 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 ca-

pacity, endurance and technique for a successful perform-
ance16. Whereas the link between dynamic muscle forces and
bone traits is well established1,2, there may be some other load-
ing related factors in alpine skiing than sole incident muscle
forces that modulate these athletes’ skeletal adaptation. For ex-
ample, very short, but high external force peaks induced by
the uneven track surface are transmitted to the lower extremi-
ties, 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 ex-
ternal forces that can vary a lot in terms of magnitude, fre-
quency and number as a function of skiing speed. The faster
the speed, the higher the magnitude and the higher the fre-
quency content of loading. For illustration, this can be seen
from hip-level accelerations recorded from two differently per-
forming recreational skiers (Figure 1). Both in training and
competition elite alpine skiers’ speed is much higher than in

| 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 |

* 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.
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. It is known that elite alpine skiing can modulate bone turnover which is necessary for bone adaptation. 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. 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. 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, but much lower than those in triple jumpers - yet sprinters have a similar bone strength advantage compared to controls as triple jumpers. 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, supported by observations in adolescent alpine skiers as well.

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. It is possible that because of the generally lower level of habitual vigorous physical activity in females 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. 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, 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. 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. Optimal influence on bone health with exercise training can be obtained particularly during the growth spur of adolescence.

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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