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Original Article

Association between long-term exercise loading and lumbar spine trabecular bone score (TBS) in different exercise loading groups

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Abstract

Objective: To examine whether different exercise loading is associated with lumbar vertebral texture as assessed with Trabecular Bone Score (TBS). **Methods:** Data from 88 Finnish female athletes and 19 habitually active women (reference group) were analyzed. Participants' mean age was 24.3 years (range 17-40 years). Athletes were divided into five specific exercise loading groups according to sport-specific training history: high-impact (triple jumpers and high jumpers), odd-impact (soccer players and squash players), high-magnitude (power lifters), repetitive impact (endurance runners), and repetitive non-impact (swimmers). TBS-values were determined from lumbar vertebral L1-L4 DXA images. Body weight and height, fat-%, lean mass, isometric maximal leg press force, dynamic peak jumping force and lumbar BMD were also measured. **Results:** Endurance runners' mean TBS value differed significantly from all other groups being about 6% lower than in the reference group. After controlling for body height, isometric leg press force and fat-%, the variables found consistently explaining TBS, the observed between-group difference remained significant (B=-0.072, p=0.020). After controlling for BMD, the difference persisted (B=-0.065, p=0.016). There were no other significant adjusted between-group differences. **Conclusion:** Exercise loading history comprising several repeated moderate impacts is associated with somewhat lower TBS, which may indicate specific lumbar microarchitecture in endurance runners.

Keywords: Athletes, Bone architecture, Bone density, Exercise, Osteoporosis

Introduction

Bone tissue, particularly its geometry and structure, adapts to habitual physical loading[1,2]. Athletes provide an appropriate natural model to study associations between long-term exercise loading and various bone traits. Currently, the clinical assessment of the axial skeleton relies mainly on dual energy X-ray absorptiometry (DXA) measured areal bone mineral density (BMD)3. However, areal BMD is an aggregate measure of several bone traits reflecting both volumetric bone mineral apparent density and bone size (ie, ~area-adjusted bone mass) without being able to reveal microarchitectural properties or actual cross-sectional geometry of the bone[4]. Since cortical bone accounts for more of the total bone mass and apparent density than trabecular bone, changes in trabecular structure need to be substantial to become detected[5]. Thus, a comprehensive insight into bone strength would require relevant information about bone structure and quality, beyond the limited information provided by areal BMD[3]. For example, the same BMD in two individuals does not necessarily mean the same bone strength due to specific variation in trabecular microarchitecture and cortical geometry[5].

Recently a novel bone texture parameter called Trabecular Bone Score (TBS) was introduced. The TBS values are calculated from the planar DXA-image data obtained from lumbar vertebrae. The TBS analysis quantifies local variation between pixel grey-scale intensities within the bone projection, and the TBS-values reflect bone microarchitecture[6-9]. Specifically, TBS values correlate positively with the number of trabeculae and their connectivity and negatively with the distance between trabeculae. Accordingly, a high TBS indicates dense

The authors have no conflict of interest.

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bone microarchitecture with little space between the well-connected trabeculae[7,10,11]. In contrast, low TBS values have been shown to strongly associate with many of the risk factors for vertebral fractures including recent glucocorticoid use, prior major fracture, rheumatoid arthritis, chronic obstructive pulmonary disease, high alcohol intake, and low body mass index[5,12]. Given the fact that exercise loading can modify bone structure it should also affect lumbar TBS, but this, to our knowledge, has not yet been shown.

Osteogenic exercise at the lumbar spine region appears to come in several effective modalities[13]. Dynamic loading at high strain rates and/or from unusual directions seems to be particularly osteogenic (high- and odd-impact loading)[14,15]. Similarly, application of high magnitude loading (heavy weight-bearing) appears effective as well[16,17]. In contrast, highly predictable repetitive loading with lower weight-bearing and impact levels does not appear to yield bone benefits (repetitive moderate impact and non-impact)[14,16,17].

In this study of competitive female athletes, we investigated whether long-term specific exercise and sports training comprising either: 1) high-magnitude vertical impacts (high impact), 2) moderate impacts from rapidly varying unusual directions (odd-impact), 3) high-magnitude weight-bearing, 4) a large number of muscle forces repeated at a high rate accompanied by moderate impacts from typical loading directions (repetitive impact), or 5) non-impact and non-weight-bearing muscle forces repeated at a high rate (repetitive non- impact) is associated with higher lumbar spine TBS compared with habitually physically active participants not engaged in any sport-specific training or competitions. In addition, we also assessed whether maximal isometric and dynamic muscle performance were associated with TBS.

Materials and methods

Subjects

Previously collected data from 88 Finnish female athletes competing at a national or international level and 19 non-athletic but habitually physically active females were analyzed in this study[14]. Participants' mean age was 24.3 years (range 17-40 years). They were all postpubertal and premenopausal.

The athletes represented seven different sports and were divided into five groups according to the loading types based on their sport-specific training history[18]. The groups were comprised of 9 triple-jumpers, 10 high jumpers, 9 soccer players, 9 squash players, 17 power lifters, 17 endurance runners and 17 swimmers. The triple-jumpers and high jumpers comprised the high-impact group, and the soccer and squash players comprised the odd-impact loading group. Power lifters (high-magnitude), endurance runners (repetitive impact), and swimmers (repetitive non-impact) comprised the remaining three groups.

The athletes were recruited via national sport associations, whereas the non-athletic reference participants were mainly local physiotherapy and nursing students. All participants gave a written informed consent before the study. The study protocol was approved by the ethics committee of The Pirkanmaa Hospital District.

Methods

Body height (cm) and weight (kg) were measured with standard methods, without shoes in light indoor clothing. Training history of five preceding years was recorded with a questionnaire including information on weekly sport-specific training hours and number of training sessions. Medications, diseases, menstrual status, use of hormonal contraceptives, calcium intake, alcohol, tobacco and coffee consumption, previous injuries and fractures were also recorded.

Areal BMD of the lumbar spine (vertebrae L1-L4) was measured with DXA (Lunar Prodigy Advance, GE Lunar, Madison, WI, USA). TBS values of the same lumbar vertebrae were determined from DXA images with dedicated analysis software (TBS iNsight, Medimaps Group SA, Geneva, Switzerland). Fat-% and lean (muscle) mass were also measured with DXA.

Maximal isometric force of the lower extremities was assessed at 90° knee flexion angle with a leg press dynamometer (Tamtron, Tampere, Finland). Dynamic performance of the lower extremities was assessed by measuring the peak take-off force during a counter-movement jump (CMJ) test with force plate (Kistler Ergojump 1.04, Kistler Instrumente AG, Winterthur, Switzerland). In the CMJ test, the participant in the standing position kept her hands on the pelvis to prevent arm swing. Then she made a downward movement by flexing her knees and hips at her preferred rate and depth, and immediately thereafter extended her knees and hips in order to jump vertically as high as possible.

Statistical analyses were done with SPSS for Windows (version 20; IBM Inc., Chicago, IL.). Means, standard deviations (SD) and ranges are given as descriptive statistics. One-way analysis of variance (ANOVA) with Sidak-correction was first used to evaluate TBS differences between the exercise loading groups. Then analysis of covariance (ANCOVA) was used to estimate between-group differences in TBS-values. Backward, forward and stepwise multiple regression analyses were used to seek for the most consistent confounding variables to be used as covariates. Age, age-squared, height, weight, lean mass, fat-%, maximal isometric leg press force and jumping peak force were served to the regression analyses. The group comparisons were also separately controlled for lumbar spine BMD after adjusting for the covariates obtained from the regression analyses.

In addition to within-group and the pooled group correlations between lumbar spine TBS and BMD, relationships between maximal isometric and dynamic muscle forces and lumbar TBS and BMD in each loading group and in the pooled group were determined. A p-value of less than 0.05 was considered statistically significant.

Results

Table 1 shows descriptive characteristics for age, height, weight, fat-%, lean mass, and and Table 2 for leg press and jumping forces in each exercise loading group. In general, ath-

Exercise loading group	N	Age (years)	Height (cm)	Weight (kg)	Fat-%	Lean mass (kg)
High-impact	19	22.3 (4.1) [16.8–32.0]	174 (5.9) [165 – 186]	60.2 (5.4) [55.0 – 73.2]	20.0 (3.9) [9.0–27.8]	45.9 (3.1) [41.4–52.8]
Odd-impact	18	24.4 (5.3) [18.3 – 35.3]	165 (8.3) [157 – 189]	61.4 (8.2) [47.4 – 79.8]	25.6 (5.7) [17.5 – 39.6]	43.5 (4.3) [35.6 – 52.6]
High-magnitude	17	27.5 (6.3) [18.4 – 40.2]	158 (3.5) [153 – 167]	63.3 (13.2) [47.9 – 106.3]	27.9 (7.4) [17.5 – 38.6]	43.2 (5.9) [35.5 – 63.5]
Repetitive impact	17	29.1 (5.7) [19.9 – 38.6]	168 (5.0) [158 – 176]	53.6 (3.4) [44.0 – 58.3]	13.9 (3.5) [9.4 – 20.4]	44.2 (3.2) [36.4 -49.6]
Repetitive non-impact	17	19.6 (2.4) [17.0 – 25.3]	173 (4.5) [165 – 179]	65.5 (5.5) [53.0 – 78.3]	25.0 (5.6) [15.0 -35.2]	47.0 (3.4) [40.8 – 52.8]
Reference	19	23.4 (3.6) [19.9 – 32.6]	165 (5.3) [150 – 174]	60.5 (7.2) [44.2 – 70.4]	32.0 (5.9) [21.6 – 40.1]	39.2 (4.3) [32.4 - 49.5]

Table 1. Age and anthropometric characteristics (mean, SD, range) in the exercise loading groups.

Exercise loading group	Jumping peak force (kN)	Relative jumping peak force (xBW)	Maximal isometric leg press force (kN)	Maximal isometric leg press force (xBW)
High-impact	1.80 (0.39) [1.24 – 3.02]	2.98 (0.47) [2.20 – 4.12]	1.89 (0.40) [1.29 – 2.64]	3.15 (0.74) [2.27 – 4.70]
Odd-impact	1.57 (0.30) [1.18 – 2.03]	2.55 (0.35) [2.03 – 3.09]	1.86 (0.38) [1.27 – 2.82]	3.04 (0.58) [2.04 – 4.21]
High-magnitude	1.66 (0.31) [1.10 – 2.31]	2.66 (0.39) [2.05 – 3.51]	2.22 (0.38) [1.20 -3.08]	3.55 (0.53) [2.81 – 4.89]
Repetitive impact	1.41 (0.28) [1.07 – 2.10]	2.65 (0.53) [1.96 -4.03]	1.68 (0.46) [1.18 – 2.80]	3.13 (0.79) [2.15 – 5.03]
Repetitive non-impact	1.57 (0.18) [1.15 – 2.03]	2.41 (0.27) [1.92 -3.12]	1.74 (0.40) [1.15 -2.70]	2.67 (0.59) [1.67 – 3.95]
Reference	1.42 (0.19) [1.15 – 1.83]	2.36 (0.26) [1.95 – 2.92]	1.43 (0.26) [0.96 – 2.03]	2.37 (0.40) [1.77 – 3.14]

Table 2. Muscle force characteristics (mean, SD, range) in the exercise loading groups.

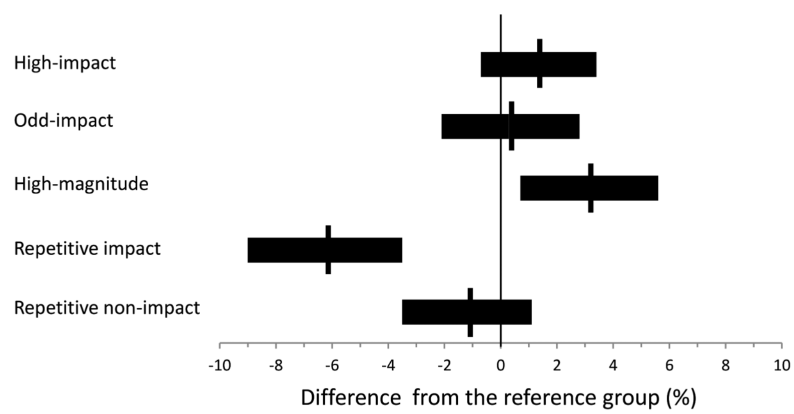

Figure 1. Mean crude percentage group-differences in lumbar Trabecular Bone Score (TBS) with 95 % confidence intervals (black bar) in relation to the reference group. The black line in the middle of each bar denotes the mean value.

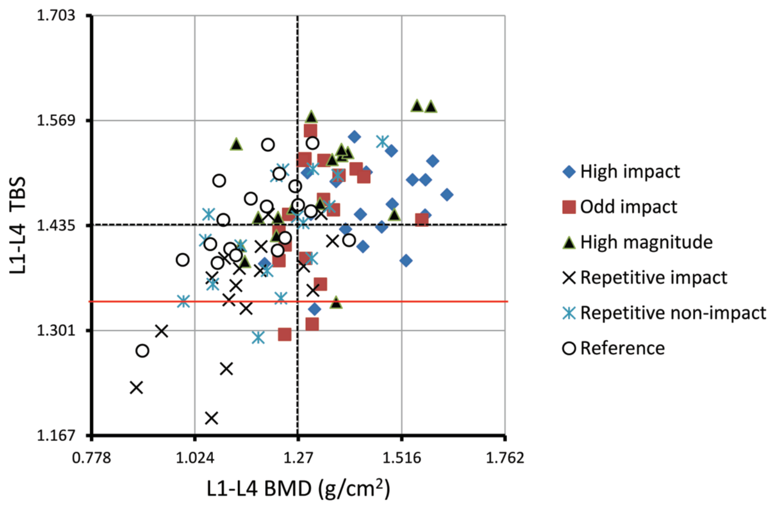

Figure 2. Relationship between unadjusted lumbar Trabecular Bone Score (TBS) and areal bone mineral density (BMD) in the exercise loading groups. The dotted bold lines indicate the mean TBS and BMD values in the pooled group while the thin solid lines indicate 2 SD deviation from the corresponding mean. The red thin line denotes the TBS value of 1.35 indicating somewhat degraded trabecular structure.

letes were leaner and stronger than their non-athletic counterparts. The non-impact group (swimmers) was the youngest group, while the repetitive impact-group (endurance runners) was the oldest. Fat-% was highest in the high-magnitude group (weight lifters), and lowest in the repetitive impact group. There were no amenorrheic women in any group at the time of DXA scans.

Table 2 shows descriptive characteristics for lumbar TBS and BMD values in different exercise loading groups. Figure 1 illustrates the crude group-differences in TBS (together with 95% confidence intervals) in relation to the mean of the reference group. Endurance runners' mean TBS was significantly lower compared with all other groups. Their mean TBS was about 6% lower compared with the reference group. Power lifters had about 3% higher mean TBS compared with the reference group. No other significant between-group differences were observed.

As to the search for confounding variables, only age and age-squared were removed by the backward regression analysis. Forward regression analysis indicated that maximal isometric leg press force (standardized β=0.312, p=0.001), height (standardized β= -0.248, p=0.006) and fat-% (standardized β=0.212, p=0.017) provided the best model which was also confirmed by the stepwise regression analysis. Therefore these three variables were used as covariates in the group comparisons.

After controlling for body height, isometric leg press force and fat-%, the observed crude difference among the endurance runners remained significant (B= -0.072, p=0.020). After controlling for lumbar BMD, the difference still persisted (B= -0.065, p=0.016). Other exercise loading groups' adjusted TBS values did not differ significantly from the reference group.

The relationships between lumbar TBS and BMD within the exercise loading groups are illustrated in Figure 2. In the

Group	TBS (unitless)	BMD (g/cm²)
High-impact	1.46 (0.06) [1.328 – 1.548]	1.44 (0.12) [1.190 – 1.624]
Odd-impact	1.45 (0.07) [1.296 – 1.556]	1.32 (0.09) [1.224 – 1.564]
High-magnitude	1.48 (0.07) [1.337 – 1.588]	1.32 (0.14) [1.123 – 1.586]
Repetitive impact	1.35 (0.07) [1.189 – 1.450]	1.15 (0.13) [0.885 – 1.352]
Repetitive, non-impact	1.43 (0.07) [1.292 – 1.542]	1.22 (0.13) [0.997 – 1.471]
Reference	1.44 (0.06) [1.275 – 1.540]	1.17 (0.12) [0.899 – 1.391]

Table 3. Lumbar vertebral (L1-L4) TBS and BMD values (mean, SD, range) in the exercise loading groups.

whole group, TBS and BMD were moderately correlated (r=0.52, p<0.001), whereas between the loading-specific groups there was a lot of variation in group-specific associations. The highest correlation was found in the repetitive impact group (r=0.68, p<0.01), followed by the repetitive non-impact and reference group (r=0.60 in both, p<0.01), the high-magnitude group (r=0.51, p<0.05), the high-impact group (r=0.36, p=ns), and the odd-impact group (r=0.30, p=ns).

Correlations between lumbar spine TBS and BMD and lower extremity muscle performance in each exercise loading group and for the whole group are shown in Table 3. In the high-impact group, the correlation between maximal isometric leg press force and TBS was significantly positive, as was the correlation between peak jumping force and TBS. In the high-

Group	TBS vs. leg press force	TBS vs. jumping force	BMD vs. leg press force	BMD vs. jumping force
High-impact	**0.46**	**0.49**	0.26	0.25
Odd-impact	0.09	-0.14	0.16	0.39
High magnitude	0.12	0.09	**0.55**	**0.54**
Repetitive impact	0.43	-0.09	0.27	-0.02
Repetitive non-impact	0.37	-0.21	0.32	-0.07
Reference	0.16	0.35	0.08	0.22
Pooled group	**0.34**	**0.22**	**0.41**	**0.44**

**significant (p<0.05) are given in bold face.*

Table 4. Unadjusted univariate correlations* between lumbar spine bone traits (TBS and areal BMD) and muscle performance in the exercise loading groups.

magnitude group, leg press force and jumping force correlated significantly positively with BMD, but not with TBS. There were no other significant correlations in exercise loading groups whereas all correlations were significant in the pooled data of all groups.

Discussion

In this cross-sectional study of 88 female athletes representing different types of skeletal loading and 19 habitually physically active young women, we examined whether long-term, sport-specific exercise was associated with lumbar vertebral texture, as assessed by TBS analysis of DXA images. To our knowledge, this kind of study has not been done before. We found that athletes experiencing a large number of monotonous impacts (repetitive, moderate impact loading represented by endurance runners) in their training and competition had significantly lower TBS compared with all other groups including the reference group, whereas the athletes experiencing extreme axial loading (high-magnitude loading represented by power lifters) had somewhat higher crude TBS values compared with the reference group. Recently, power lifting was also found to be associated with the different texture at the superior region of the femoral neck[19].

Several studies have found moderate-to-strong correlation between TBS values and actual 3D microarchitectural parameters of vertebral bodies (volumetric density, cortical thickness, trabecular number, thickness and separation, and structural model index) both *ex vivo* and *in vivo*[6-9]. Therefore the present TBS observations in endurance runners and power lifters may reflect specific differences in their vertebral microstructure, the former having possibly less strong and the latter having more robust trabecular architecture of lumbar vertebrae. It is noted, however, that the mean TBS values in all groups but endurance runners were clearly higher than the threshold TBS value of 1.35 considered to indicate somewhat degraded microstructure[9]. Also, only 11 (10%) individuals out of 107 participants had lower TBS than the above threshold, but five of them were endurance runners. Be it noted, however, that at least one individual in each group had a TBS below the above mentioned threshold.

The TBS difference observed among endurance runners remained significant after adjustment for relevant anthropometric and force variables indicated consistently by multiple regression analyses. As to the clinically used lumbar BMD, highest values have been observed in the high- and odd-impact groups (about 25% and 15% higher compared to reference group[14]. Evidently the TBS data conveys different, independent information on bone structure beyond areal BMD. Interestingly, the strongest association between TBS and BMD was observed in endurance runners, followed by swimmers and physically active reference subjects. In contrast, the higher the impacts or the higher the loads involved in sport-specific loading, the weaker the correlation with TBS values. It may be so that a denser trabecular structure (possibly manifest as thicker and less separated trabeculae within the given bone volume) both in vertical and horizontal directions is likely required to safely withstand high impacts or axial loadings. Apparently the same applies to impacts from varying unusual directions. It is also possible that the vertebral architecture of endurance runners represents a structure that is particularly adapted to a large number of monotonous moderate vertical impacts, and this specific textural feature is captured by TBS. In contrast, bone structural information representing specific spatial distribution of bone tissue cannot be captured by the DXA-measured areal BMD which basically reflects the mean effective thickness of bone mineral within the bone volume of interest but is unable to separate spatial structural features from each other neither within the plane nor in depth direction[4,20].

The link between muscle performance and bone strength is well established[1,2]. In the present study, lower extremity muscle performance was significantly associated with TBS in the high impact group and with lumbar BMD in the high magnitude group, but not vice versa. While interesting, these group-specific correlations do not allow making conclusions about whether dynamic or isometric muscle performance is more consistently associated with TBS. It is also reminded that the used muscle force variables are not specific indices of lumbar muscular function nor the habitual loading of lumbar vertebrae. However, isometric leg press force may reflect better the general strength status of an individual than the jumping performance. Further studies with more appropriate force assessments are needed to establish the potential relation of exercise-specific functional loading to TBS.

The major strengths of the present study are the large total sample of athletes representing distinct long-term exercise histories and the data on actual muscle performance. Also a habitually physically active reference group can be considered a strength. Apparently this kind of an active reference group did not exaggerate the magnitude of differences observed in bone traits compared with athletes. It rather represents a mixture of various loading patterns performed at lower intensity and duration. Thus it is likely that specific loading-induced features in the lumbar spine texture as captured by TBS analysis are revealed, should such differences truly exist. The present study thus adds to the literature by providing novel TBS data on female athletes who have been subjected to well-documented specific and intensive loading patterns over long periods of time, about 10 years on average.

There are some limitations that need to be addressed. First, while none of the athletes was amenorrheic at the time of the present study, we did not have information on whether they had menstrual irregularities during the period of rapid growth or delayed puberty because of intensive physical training in youth. Thus, the possibility that the lumbar trabecular architecture was somehow compromised due to hormonal abnormalities already in adolescence cannot be ruled out. Future studies should evaluate larger athlete groups representing specific exercise loading patterns. In the future studies attention should be paid on obtaining relevant information on the specific contents of training and exercise during the adolescent growth spurt, besides the present data, and also on the hormonal status at different ages. Second, the self-selection bias is always a concern in cross-sectional studies of athletes; obviously initially strong and biomechanically fit individuals are more likely to start specific athletic career. Thus, matching of groups in terms of anthropometric or physical performance characteristics may be challenging. On the other hand, height explained only 10% of variance in TBS (data not shown) and in many athlete groups, muscle force accounted only for a few % of variance in TBS (Table 3). Third, participants' wide age range from 17 to 40 years and almost a 10 year difference between the mean age of endurance runners and swimmers may be considered a concern, too. However, age together with its quadratic term along with several relevant confounders was controlled for in the statistical analysis and the TBS-differences between groups remained yet significant. Of note, in the pooled group, age accounted for only 0.3% of the variance in TBS (data not shown). Fourth, it is recalled that the limited spatial resolution and projectional nature of the DXA image impedes accurate analysis of actual trabecular architecture while TBS remains a proxy of trabecular structure. Evidently TBS provides independent information beyond BMD but its physical interpretation in concrete structural terms remains ambiguous. Further studies should thus seek information on actual three-dimensional structural features of vertebral bodies in different athlete groups, e.g. using sufficiently high-resolution data from quantitative computed tomography or magnetic resonance imaging, as appropriate.

In conclusion, TBS analysis of lumbar DXA images provides a quantitative method for detecting differences in apparent trabecular architecture of lumbar vertebrae that are related to specific long-term exercise loading patterns. In particular, we found that high-magnitude loading typical of power lifting is associated with slightly higher TBS values whereas repetitive impacts typical of endurance running are associated with somewhat lower TBS values independent of lumbar spine BMD.

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