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Bone Mineral Density in Athletes of Different Disciplines: a Cross-Sectional Study

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Abstract: *Background:* The objective of this study was to assess bone mineral density (BMD) of the lumbar spine and the proximal femur in male and female athletes performing different high level sports, in unspecifically trained sport students and in untrained subjects.

Methods: BMD of lumbar spine and proximal femur were measured by dual-energy-x-ray-absorptiometry in 209 female and 173 male subjects aged 17-30 years (37 runners (R), 16 cyclists (C), 22 triathletes (TRI), 62 team sport athletes (TS), 45 combat/power athletes (P), 13 ballet dancers (BL), 126 sport students, 61 untrained controls (UT)).

Results: Highest BMD values were found in P and TS. Lowest values were found in UT, BL, and endurance trained athletes (R/C/TRI).

Conclusions: BMD is probably dependent on the specific mechanical demands of different sports.

Keywords: Exercise, metabolic bone disease, DXA scan, sports medicine.

INTRODUCTION

Osteoporosis is a systemic disease of the skeleton with reduced bone mass and structural deterioration of the bone tissue, resulting in a higher incidence of fractures. Bone structure and bone tissue metabolism are determined by the individual genetic predisposition and the influence of endocrine and mechanical factors [1-3]. The knowledge of the mechanisms of skeletal adaptation to mechanical loading and to metabolic conditions caused by physical activity is essential to prevent osteoporosis. Athlete studies can help to identify potential risks in young people for developing osteoporosis in their later years. Cross-sectional studies in athletes revealed that different types of exercise cause different effects on bone remodelling [4-6]. It is so far unknown, which component of stress has the strongest anabolic effects on bones in humans: kind of stress, intensity, frequency or duration? Experiments with animals revealed that new bone formation depends less on duration of mechanical stress but more on its magnitude and rate: especially strains of high rate and magnitude stimulated new bone formation [3]. One of the most important factors influencing bone metabolism in humans probably is impact force that causes compression (e.g. spine) or deflection (e.g. proximal femur) of bones [3]. Moving our body under earth's gravity by itself seems to be one of the largest stimuli to increase bone mass. Removing gravity eliminates strain on bone and causes significant bone mineral density (BMD) losses in astronauts [7]. Another factor that affects bone metabolism is bone strain caused by muscle contraction leading to local adaptations in bone density at tendon insertion sites. High bone mineral densities found in weight-lifters can be explained by these mechanisms [8]. Furthermore, hormonal factors may influence bone mass. Exercise is accompanied by complex hormonal regulation mechanisms depending on recruited muscle mass, duration and intensity of activity, age and gender. Calcium regulating hormones, thyroid hormones [9], human growth hormone (hGH), insulin-like growth factor-I (IGF-I) [10], as well as male and female sex hormones [11, 12] are affected by physical activity and were found to be predictors of total bone density.

In an aging population the prevention of osteoporosis becomes more and more important. The individual maximal bone mass is probably reached with the age of twenty [13], so that an effective prevention of osteoporosis should start in adolescence. Some longitudinal studies suggest that exercise induced increase in BMD obtained in adolescence can be maintained into adulthood despite reduced adult physical activity and may reduce fracture risk in the senium. Adolescence and early adulthood seem to offer the unique opportunity to optimize peak bone mass [14].

Unfortunately, physical activity and training do not always have positive effects on bone metabolism. Under certain conditions high level sports and even ambitious recreational sports can affect bone mass adversely. Even high levels of training may not help to increase or even lower BMD, when the kind of mechanical loading of the skeleton is inadequate or if other components of bone metabolism (e.g. nutrition, hormonal balance) are affected. There are a number of athlete studies that describe low BMD especially in sports where body weight can be a limiting factor for performance, where high training volumes are common and where the reproductive function can be altered, for example in long-distance running and cycling [11, 12, 15].

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The aim of this study was to assess bone mineral densities of the lumbar spine and the proximal femur in athletes performing different high level sports, and to compare them among each other, to unspecifically trained sport students and to untrained subjects.

METHODS

Study Participants

Two hundred and nine female and one hundred and seventy-three male subjects were enrolled for the study (age range 17-30 years). The sample included six groups of high level athletes: middle or long distance runners (R, n = 37; 21 males, 16 females), team sport athletes (soccer, handball, volleyball, basketball, TS, n = 62; 25 males, 37 females), cyclists (C, n = 16; 12 males, 4 females), triathletes (TRI, n = 22; 18 males, 4 females), combat/power athletes (wrestlers and judoists, P, n = 45; 28 males, 17 females) and ballet dancers (BL, n = 13 females); one group of unspecifically trained sport students (STU, n = 126; 44 males, 82 females) and one group of untrained subjects (UT, n = 61; 25 males, 36 females). All athletes had a history of at least 4 years of specific training in their sport, 4 times per week and/or 6 hours per week. They were on national and, partly, international performance level. The sport students had several practical courses in many different sports in the context of their studies at the German Sport University Cologne. All untrained subjects reported less than 2 hours of sporting activities per week.

Every participant was interviewed and filled in a questionnaire on data concerning possible risk factors, family history, physical activity, training regimen, dietary intake, alcohol, smoking and medication. None of the participants was taking medications or drugs affecting bone and muscle metabolism. To exclude an organic disease interfering with bone metabolism physical examination, venous blood and urinary tests were performed. Each participant gave written informed consent. The study was in compliance with the Helsinki Declaration and was approved by the ethics committee of the German Sport University Cologne and the German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, Munich).

Anthropometric Measurements

Height (Ht) was measured to the nearest 0.5 cm. Body weight (Wt) was measured after an overnight fast to the nearest 0.1 kg. Body mass index (BMI (kg/m^2) = Wt (kg) / (Ht (m))^2 was calculated.

Bone Mineral Density

Regional BMD was measured by a bone densitometer (QDR-1000®, Hologic Inc., Waltham, MA, USA) using dual-energy x-ray absorptiometry. The measured regions were lumbar spine (L2, L3, L4) and the femoral regions neck (NECK), trochanter (TROCH), intertrochanteric region (INTER), ward's triangle (WARDS). The region "lumbar spine" (L2-L4) is defined by the mean value of L2, L3 and L4; the region "femur" (NeTrIn) is defined by the mean value of NECK, TROCH and INTER. The same experienced investigator completed and analyzed all scans using standard analysis protocols. Phantom measurements were used for quality control during the study period. The coefficient of variation was < 1.5%.

Statistical Analysis

Means and standard deviations (SD) were calculated for the anthropometric parameters and training hours. Means, standard deviations and 95% confidence intervals for the means were calculated for BMD.

RESULTS

Anthropometric characteristics of the eight groups are reported in Table **1**.

Table 1. Anthropometric Characteristics of the Groups (Mean ± Standard Deviation (SD))

		Age [years]		Weight [kg]		Height [cm]		BMI [kg/m²]	
		Women	Men	Women	Men	Women	Men	Women	Men
Untrained controls	n	36	25	36	25	36	25	36	25
	Mean ± SD	24.7 ± 2.8	25.5 ± 2.4	63.6 ± 7.6	80.0 ± 10.9	169.5 ± 6.9	182.5 ± 6.0	22.2 ± 2.8	24.0 ± 2.8
Runners	n	16	21	16	21	16	21	16	21
	Mean ± SD	22.7 ± 3.3	21.8 ± 3.4	55.2 ± 4.7	69.5 ± 7.0	167.9 ± 5.9	180.3 ± 8.2	19.6 ± 1.9	21.3 ± 0.9
Sport students	n	82	44	82	44	82	44	82	44
	Mean ± SD	24.1 ± 2.3	25.5 ± 2.1	62.9 ± 6.3	76.5 ± 7.5	169.7 ± 6.3	182.0 ± 5.8	21.8 ± 1.7	23.1 ± 1.7
Team sport athletes	n	37	25	37	25	37	25	37	25
	Mean ± SD	24.0 ± 3.1	23.2 ± 2.1	68.1 ± 7.1	81.7 ± 7.3	173.0 ± 8.3	186.9 ± 7.1	22.8 ± 2.1	23.4 ± 1.2
Cyclists	n	4	12	4	12	4	12	4	12
	Mean ± SD	23.5 ± 2.5	19.4 ± 3.6	63.0 ± 5.6	77.0 ± 9.7	166.5 ± 3.1	183.4 ± 7.5	22.8 ± 2.3	22.8 ± 1.7
Triathletes	n	4	18	4	18	4	18	4	18
	Mean ± SD	24.3 ± 4.9	20.6 ± 3.6	62.6 ± 5.4	72.6 ± 5.5	169.5 ± 5.2	181.9 ± 5.0	21.7 ± 0.7	21.9 ± 1.5
Power/Combat athletes	n	17	28	17	28	17	28	17	28
	Mean ± SD	22.2 ± 3.4	20.7 ± 3.4	66.6 ± 7.9	80.1 ± 15.6	168.1 ± 5.3	177.9 ± 9.3	23.5 ± 2.0	25.4 ± 3.6
Ballet dancers	n	13	0	13	0	13	0	13	0
	Mean ± SD	19.3 ± 1.0		54.0 ± 5.2		163.4 ± 5.5		20.2 ± 1.3	

Hours of training per week are illustrated in Fig. (**1**).

The BMD of lumbar spine and proximal femur in the different groups are shown in Table **2**, in Fig. (**2**) (lumbar spine) and in Fig. (**3**) (femur).

In female athletes BMD of the lumbar spine was lowest in ballet dancers. Female power/combat athletes had the highest lumbar BMD, followed by team sport athletes. BMD of the femur (NeTrIn) in women was lowest in non-athletes and highest in team sport athletes.

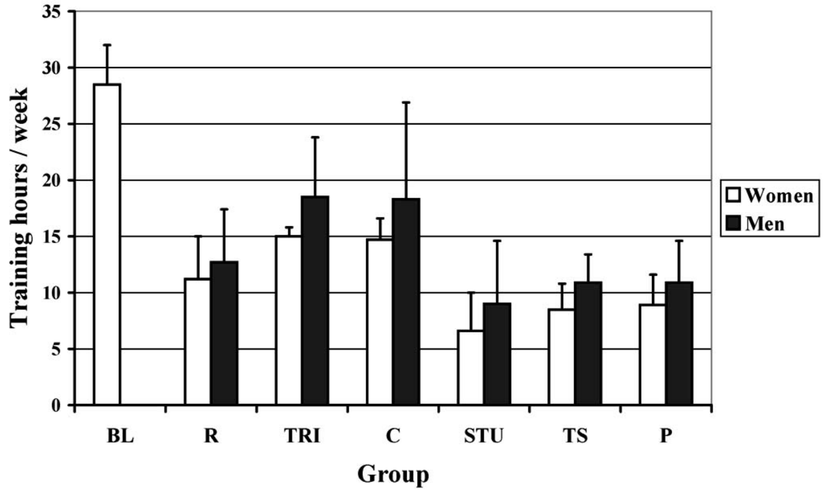

Fig. (1). Training characteristics of the different groups (mean ± standard deviation). BL=Ballet dancers; R=Runners; TRI=Triathletes; C=Cyclists; STU=Sport Students; TS=Team sport athletes; P=Power/Combat athletes.

Table 2. Bone Mineral Densities of the Groups in the Different Body Regions (Mean ± Standard Deviation (SD) and 95% Confidence Interval (CI) for the Mean)

		BMD (L2-L4) [g/cm²]		BMD (NeTrIn) [g/cm²]		BMD (Ward's Triangle) [g/cm²]	
		Women	**Men**	**Women**	**Men**	**Women**	**Men**
Untrained controls	n	36	25	36	25	36	25
	Mean ± SD	1.09 ± 0.10	1.09 ± 0.14	0.97 ± 0.09	1.06 ± 0.13	0.75 ± 0.11	0.78 ± 0.12
	CI	1.05, 1.12	1.03, 1.15	0.94, 0.10	1.00, 1.11	0.71, 0.79	0.73, 0.83
Runners	n	16	21	16	21	16	21
	Mean ± SD	1.09 ± 0.12	1.10 ± 0.13	1.01 ± 0.16	1.17 ± 0.13	0.82 ± 0.19	0.93 ± 0.13
	CI	1.03, 1.15	1.04, 1.16	0.93, 1.10	1.11, 1.23	0.72, 0.91	0.87, 0.99
Sport students	n	82	44	80	44	80	44
	Mean ± SD	1.16 ± 0.11	1.22 ± 0.13	1.06 ± 0.10	1.20 ± 0.15	0.87 ± 0.13	0.95 ± 0.17
	CI	1.14, 1.18	1.18, 1.26	1.03, 1.08	1.16, 1.25	0.84, 0.89	0.90, 1.00
Team sport athletes	n	37	25	37	25	37	25
	Mean ± SD	1.23 ± 0.11	1.28 ± 0.14	1.16 ± 0.12	1.28 ± 0.14	0.96 ± 0.14	1.04 ± 0.15
	CI	1.19, 1.27	1.22, 1.34	1.12, 1.20	1.22, 1.34	0.91, 1.01	0.98, 1.10
Cyclists	n	4	12	4	12	4	12
	Mean ± SD	1.14 ± 0.12	1.09 ± 0.11	1.05 ± 0.17	1.06 ± 0.14	0.82 ± 0.21	0.84 ± 0.14
	CI	0.95, 1.32	1.02, 1.16	0.78, 1.32	0.97, 1.15	0.48, 1.16	0.75, 0.93
Triathletes	n	4	18	4	18	4	18
	Mean ± SD	1.12 ± 0.15	1.08 ± 0.09	1.02 ± 0.08	1.14 ± 0.10	0.81 ± 0.08	0.92 ± 0.13
	CI	0.89, 1.36	1.03, 1.12	0.90, 1.14	1.09, 1.19	0.69, 0.93	0.86, 0.99
Power/Combat athletes	n	17	28	17	28	17	28
	Mean ± SD	1.29 ± 0.18	1.35 ± 0.16	1.12 ± 0.11	1.27 ± 0.14	0.96 ± 0.12	1.09 ± 0.18
	CI	1.20, 1.38	1.29, 1.41	1.06, 1.17	1.22, 1.32	0.90, 1.02	1.02, 1.16
Ballet dancers	n	13	0	13	0	13	0
	Mean ± SD	1.08 ± 0.15		1.05 ± 0.11		0.91 ± 0.12	
	CI	0.98, 1.17		0.98, 1.11		0.84, 0.99	

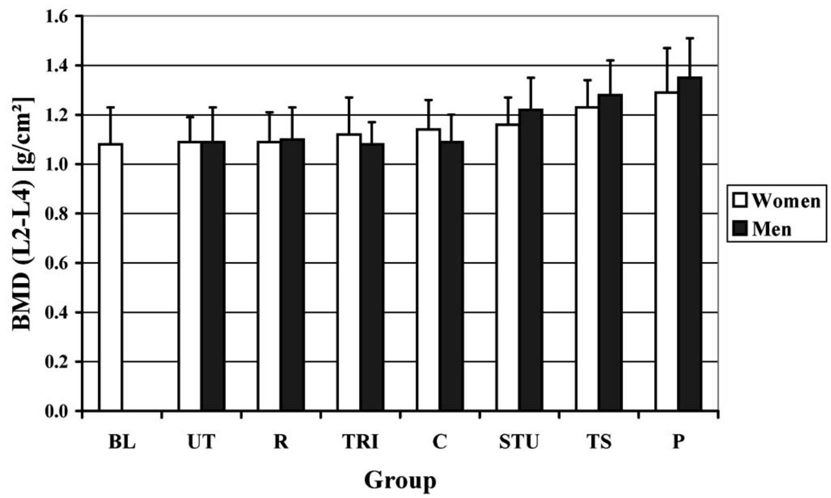

Fig. (2). Bone mineral densities of the lumbar spine (BMD L2-L4) of the different groups (mean ± standard deviation). BL=Ballet dancers; UT=Untrained controls; R=Runners; TRI=Triathletes; C=Cyclists; STU=Sport Students; TS=Team sport athletes; P=Power/Combat athletes.

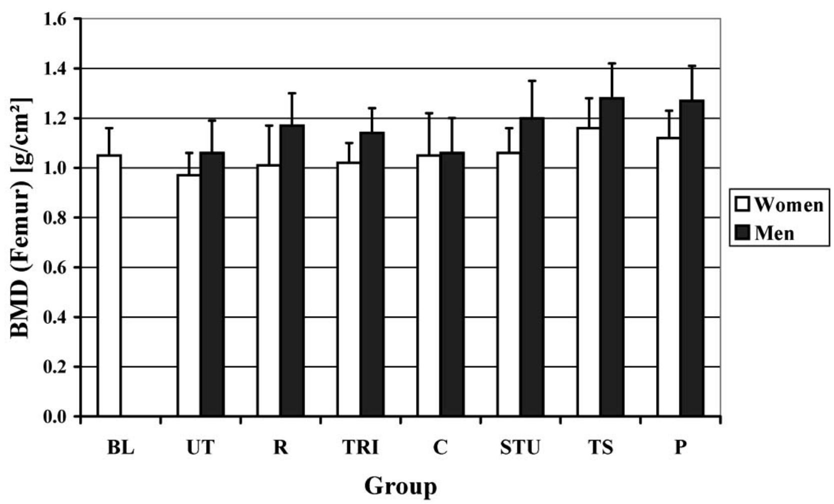

Fig. (3). Bone mineral densities of the femur (BMD Femur) of the different groups (mean ± standard deviation).

In male athletes BMD of the lumbar spine was lowest in triathletes. They were followed by cyclists, non-athletes and runners. Male combat athletes and team sport athletes had the highest lumbar BMD. The BMD of the femur (NeTrIn) was lowest in male non-athletes and cyclists. It was highest in male power/combat athletes and in team sport athletes.

DISCUSSION

This study assessed BMD of the lumbar spine and the proximal femur in a high number of young male and female athletes performing different top level sports, in unspecifically trained sport students and in untrained subjects of the same age group. The highest BMD values were found in power/combat athletes and in team sport athletes in both genders. Reasonably high BMD values were also found in the unspecifically but multidimensionally trained sport students.

Several studies have shown that weight bearing exercise (judo [16], powerlifting [8]) and high impact loading sport (soccer [17], volleyball [18], team handball [19], tennis [20]) are associated with greater levels of BMD in comparison to non-active control groups. The explanation for these results can be given by analyzing the sport-specific loads: combat sports like judo and wrestling include high-magnitude forces transmitted *via* intense muscle pulling on the bone, ground reaction forces intensified by the absence of footwear to attenuate impact shocks and high-impact loading of the skeleton by repeated falls on the ground. Sport-specific movements in the investigated ball games, like jumping, sprints and quick stoppings, also induce strains of high rate and magnitude.

There are a few investigations that compared different sporting activities to each other. Matsumoto *et al.* [5] found higher BMD in judoists than in swimmers and in long distance runners, but no significant difference between swimmers and runners. Creighton *et al.* [21] found that women who participate in impact sports such as volleyball and basketball had higher BMD and higher markers of bone turnover than female swimmers. Fiore *et al.* [4] demonstrated that canoeists had significantly higher spine, pelvic and total body BMD than cyclists and controls.

Other studies point out the site specific adaptation of the skeleton depending on the unusual strains created at certain sites during sport training by muscle stress and gravitational forces. Morel *et al.* [6] for example found higher BMD in the legs compared to other body regions in soccer players and runners, higher arm BMD in bodybuilders, fighters, climbers and swimmers and higher spine BMD in rugby players.

In the present study low BMD values of lumbar spine and femur were found in male cyclists. Triathletes and runners also demonstrated low BMD values of the lumbar spine but intermediate BMD values of the femur which may be due to the repetitive impact on the femoral neck caused by running.

In female and male endurance athletes bone loss can be associated with hormonal imbalances and nutritional deficits [11, 12]. In this context, the "female athlete triad" (menstrual irregularity, disordered eating, low BMD) that occurs mainly in endurance athletes is an extensively discussed topic in the literature. Nichols *et al.* [15] found lower bone mineral density in highly trained male master cyclists compared to their age-matched peers. This indicates that despite a high training load and a high physical fitness level, not only female but also male endurance athletes may be at risk for developing low BMD. In our study the femoral and lumbar BMD were not lower, neither in male nor in female endurance trained athletes (C, R, TRI) than in non-athletes.

In our study the lowest BMD value for the lumbar spine was found in ballet dancers. Due to their younger age (mean 19.3 years), they might not have reached their peak bone mass yet. But they might also be affected by unreported and therefore unknown hormonal or nutritional imbalances.

CONCLUSION

This cross-sectional study has shown that power/combat athletes, team sport athletes and sport students have greater BMD than endurance trained athletes, ballet dancers and non-athletes. It can be assumed that particularly dynamic sports with short, high, and multidimensional loads have strong effects on bone formation, independent of training quantity. Sport specific and body region specific effects have to be taken into account for evaluation of osteogenic effects of exercise. Training regimes with high volume but low intensities do probably not or only slightly induce osteogenic effects, while a variable training protocol with short but high forces will probably have the highest positive stimulatory effects on bone formation. However, as these conclusions derive from cross-sectional analyses, future longitudinal studies are required to prove the supposed effects of exercise on BMD.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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All authors contributed to conception and design of the study and to acquisition of data. E-HC, PP and TH performed the statistical analyses. TH drafted the manuscript. All authors revised the manuscript critically for important intellectual content.

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