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Original Investigation

Kinanthropometric profile, hip bone mineral density, and the incidence of bone stress fractures in professional middle and long-distance runners

Jakub Bałdyka[a], Anna Kopiczko[b]
[a]Department of Theory of Sport, Józef Piłsudski University of Physical Education in Warsaw, Poland
[b]Department of Human Biology, Anthropology Section,
Józef Piłsudski University of Physical Education in Warsaw, Poland

Purpose: This study aimed to identify the kinanthropometric profile, hip bone mineral density (BMD), and frequency of bone stress fracture (BSF) in professional middle-distance and long-distance runners.
Methods: Thirty-seven professional male runners participated: middle-distance runners and long-distance runners aged 23.6 ± 2.6 years with over 6 years of training experience. Kinanthropometric measurements were performed according to ISAK standards, including body composition and Heath-Carter somatotype assessment (endomorphy, mesomorphy, ectomorphy). Hip BMD, bone mineral content (BMC), and T-scores were measured using DXA at the total and femoral neck (FN) and trochanter (TR) regions. BSF history was collected through face-to-face interviews and medical records. Body Mass Index (BMI) was calculated.
Results: Middle-distance runners presented superior all bone parameters (large effect: > .8). Long-distance runners have the highest frequency of fracture incidence compared to middle-distance runners (68.5% vs 66.5%). The results of covariance analyses showed that BMD FN was significantly influenced by muscle mass (kg) and endomorphy (scores) (adj. R^2 = .56). The same effect of these two variables was noted on the T-score FN (adj. R^2 = .75). In turn, BMC FN was affected by the type of sports competition, muscle mass (kg), and endomorphy (scores) (adj. R^2 = .84). BMD TR was significantly influenced by: endomorphy (scores) and mesomorphy (scores) (adj. R^2 = .78). BMC TR was significantly affected by muscle mass (kg) (adj. R^2 = .75). In turn, T-score TR was influenced by muscle mass (kg), endomorphy (scores), and mesomorphy (scores) (adj. R^2 = .68).
Conclusions: This study demonstrated that the type of athletic training and body tissue composition had a significant impact on BMD in the hip region. The type and specificity of training in middle-distance runners had a more favourable effect on bone parameters compared to long-distance runners. This relationship may be related to the greater mechanical load resulting from greater muscle mass and more intense osteogenic stimuli.

Keywords: kinanthropometry, bone mineral status, bone stress fractures, middle and long-distance runners' group

Introduction

Kinanthropometry is an interdisciplinary field of study important for sports and physical education sciences. The term is derived from the Greek words kinein (to move), anthropos (human), and metrein (to measure). It encompasses the study of the morphological determinants of motor performance. Kinanthropometry studies the measurement and analysis of human body composition and structure in the context of increased physical activity and athletic training, biological development, and functional capacity. In recent years, kinanthropometry has become crucial in the process of morphological optimization.
Morphological optimization is a step-by-step process aiming to achieve the optimal physical structure, body composition, and somatotype for each sport's most effective sports performance.[1] Studies of athletes indicate an extensive kinanthropometry profile dependent on athletic competition. The application of kinanthropometry in sports is extensive and well-established. The use of kinanthropometry in sports diagnostics is extensive and well established. The kinanthropometric profile includes the analysis of a number of important elements such as somatic measurements, the measurement of body tissue fossils, and the assessment of body typology, including the contribution of endomorphy, mesomorphy, and ectomorphy to the athlete's somatotype. Kinanthropometry is also an analysis of the proportions of various anthropometric dimensions, as well as an evaluation of anthropological indices. The somatic part of the kinanthropometric profile, in conjunction with the assessment of motor and functional fitness, range of motion, can be a valuable tool not only for scientists but especially for coaches and practitioners. Kinanthropometry can be very helpful in the process of training optimization. [2,3,4]
Kinanthropometric profile in high-performance sports is also an assessment of body structure and including the skeletal system, the regularity of its structure, bone mineral status, and mechanical strength of the bones. Running is a common recreational and competitive exercise,[2,5] but running-related injuries are common, with rates of musculoskeletal injuries ranging from 19% to 78%.[6,7] The basic parameters of a runner's training are volume and intensity. Training is adapted to the needs of the distance that athletes cover during sports competition. Given that athletes have the highest rate of bone stress fractures (BSF) compared to

other sports, a bone profile seems to be an important element in monitoring runners.[8,9]

Skeletal health is important for athletes at every level. Exercise has a significant impact on bone health, not only during an athletic career but throughout the lifespan, and appears to be a good candidate for preventive intervention.[10,11]

The magnitude of stresses that act on bone through muscle contractions during exercise and under gravitational forces are key elements of the concept of mechanostat theory (MT). MT states that the qualitative response of bone tissue to different levels of mechanical loading depends on the dose and direction of forces. MT indicates that the effect of pressure forces on bone tissue has a significant impact on the processes of resorption, regeneration, and new bone formation. Mechanostat, therefore, functions as a homeostatic mechanism. It involves stabilizing bone structure and mass in response to changing mechanical demands. Maintaining bone mass requires exceeding the minimum effective strain (MES) threshold. Strain levels below this threshold lead to bone degradation, whereas exceeding it initiates osteogenic processes, resulting in increased bone mass and cross-sectional area, thereby enhancing structural strength.[12]

A strong bone micro-architecture and optimal mineralization of bone tissue are critical to his or her athletic performance, physical fitness, and long-term sports career. Adequate bone health ensures an athlete's ability to continuously participate in intense training, competition, and recovery after exercise, uninterrupted by injury. Studies have shown that an athlete with higher bone mineral density (BMD) is more likely to avoid injury and recover more quickly from potential injuries.[13]

Studies have proven a strong correlation between BMD and BSF.[14,15] BSF in sports medicine are described as partial or complete bone fractures. The cause of these fractures is repeated micro-injuries to the bones, rather than a single injury. The main cause is excessive stress on the bones that exceeds their ability to regenerate. This phenomenon leads to a gradual weakening of the bone structure and, consequently, a fracture. Running is the most common sports activities that result in stress fractures.[16] According to some studies BSF accounts for nearly 30% of all runner injuries. The risk of BSF in different athletic competitions varies. Many factors influence it. It has been shown that factors influencing the development of BSF in runners can be related to bone health and body composition (i.e., fat mass and lean mass), such as low body fat percentage, low muscle mass, and low BMD.[17] However, the study does not fully describe the risk model and should be continued and expanded with multivariate analyses.[18,19] Current research reveals a significant gap that requires further investigation. Previous studies on bone stress fractures (BSF) have mostly focused on selected risk factors. Among them, the amount of training loads or environmental influences was most often analyzed. However, they did not consider a comprehensive and integrated kinanthropometric approach. In particular, few studies have included broad kinanthropometric profiling, which analyses both somatic and skeletal parameters in relation to the characteristics of stress fractures, including their etiology, anatomical location, and incidence of occurrence.[20]

The results of our study can help fill this gap. The comprehensive kinanthropometric profile used in this study will allow us to do so. Our study's methodology integrates body measurements and bone properties with a detailed analysis of BSF-related parameters. This creates opportunities for a better overall understanding of the relationship between body composition, biomechanical functions and BSF risk. In doing so, this research makes a significant contribution to the field of physical culture and sport sciences by proposing an innovative and comprehensive diagnostic methodology, with potential applications in both injury prevention and the design of individualized training and rehabilitation programs.

This study aimed to identify the kinanthropometric profile and hip bone mineralization status of Polish Athletes from the middle and long-distance runners' group. We also analyzed the frequency, etiology, and location of BSF and their correlation with hip BMD. We hypothesize that differences in bone stress fracture patterns and their associations with anthropometric characteristics can be observed between middle- and long-distance runners.

Methods

Participant

The study involved 37 Polish professional athletes: middle-distance runners (n=18; aged 23.9±3.2 years) and long-distance runners (n=19; aged 23.4±1.8 years). The middle- and long-distance running events comprise the 800m, 1500m, 3000m steeplechase, 5000m, 10,000m, and marathon. The runners surveyed had an average of 9.6 ± 2.1 years of training experience in professional sports. All participants were of the same ethnic origin (Caucasian). Athletes are participants and medallists at the National Championships and European Indoor and Stadium Championships. Inclusion criteria were as follows: written consent to participate in the study and the lack of health contraindications to densitometry. The exclusion criteria: athletes who have diseases that affect metabolic bone disorders, such as kidney disease, cancers, rheumatoid arthritis, rickets, bone diseases, nutritional disorders, and long-term steroid treatment, were not included in the analysis of results in this study. All participants were informed about the aims and schedule of the study and received their test results along with an interpretation. All athletes included in the study gave written informed consent to participate in the study.

Kinanthropometric measurements

Several necessary kinanthropometric measurements were carried out. The method of measurement, the measurement tools used, and the measurement procedure followed the guidelines of the International Society for the Advancement of Kinanthropometry (ISAK).[21] Measurements entered into the database were made by a qualified anthropologist with over 15 years of experience working with anthropometric and kinanthropometric methods. The measurements were performed by the same measurer, using the same instruments and measurement techniques for each participant. The measurement was taken in the morning, without shoes. Body weight (kg), fat mass (FM, kg), lean body mass (LBM, kg), and muscle mass (MM, kg) were measured using the bioelectrical impedance method. Measurement was taken in the morning, fasting, without clothing, on the Javon Medical Body Composition Analyzer Model X-SCAN PLUS II, Korea (Certificate No. EC0197 for medical devices), measurement range 100 - 950 Ω with a precision of .1 kg. Body height (cm) was measured using a stadiometer type Seca 264 (Seca GmbH & co.kg, Germany) with Seca 360° wireless technology, equipped with a heel positioner and Frankfurt plane positioner for head positioning with a precision of .1 cm.

The Heath–Carter (H-C) anthropomorphic somatotype method defined body shape and composition in terms of endomorphy, mesomorphy, and ectomorphy (scores).[22,23] According to Heath and Carter, ten anthropometric dimensions are measurements to calculate the anthropometric somatotype. Measured four skinfolds from the triceps (mm), subscapular (mm), supraspinal

(mm), and medial calf (mm) (Harpenden Skinfold Caliper, British Indicators, West Sussex, UK). Measured two bone breadths: humerus and femur (cm) (GPM big and small spreading caliper, Zurich, Switzerland). Measured two girths (cm): relaxed arm girths, flexed arm girths, and calf girths (Holtain anthropometric tape, Crymych, UK). Quantitative values derived were categorized on an H-C score scale, defining values of 0 to 2.5 as low, 3 to 5 as moderate, 5.5 to 7 as high, and above 7 as very high.[23]

Methods for assessing bone mineral density and incidence of bone stress fractures

Bone mineral density (BMD, g/cm^2), bone mineral content (BMC, g), and T-scores of nondominant hip total and subregions: femoral neck (FN), trochanter (TR) were measured by the densitometry method (dual-energy X-ray absorptiometry, DXA). All bone measurements were taken on a Norland XR-46 bone densitometer (Swissray-USA, Norland Medical Systems Madison WI, USA). T-score was calculated using the following formula: patient's BMD – young normal mean/SD of young normal. The precision error, expressed as the coefficient of variation (CV), was .85% during the study period. DXA scans (total and subregional) were obtained for all participants included in the present study and were performed by certified radiology technicians. According to the densitometric testing procedure and recommendations of the International Society for Clinical Densitometry, the scanner was calibrated daily. The calibration was performed against the standard calibration block supplied by the manufacturer to control for possible baseline drift.[24]

A face-to-face health interview was conducted with participants, and analysis of the available medical records of past fractures. Among runners declaring a history of bone stress fractures (BSF), data were additionally collected on diagnosis and treatment at the Specialized Sports Medicine Clinic. BSF was determined clinically as an area of marked focal, bony tenderness in association with evidence of a fracture on plain radiographs or magnetic resonance (MR) images. It was collected regarding the history, etiology, and location of the fracture from the personal documentation from the Specialized Sports Medicine Clinic, with the agreement of participants and following the Personal Data Protection Regulation (RODO) and the Law on Patients' Rights.

Statistical analysis

All data analysis was done in the program using Statistica software (v.13.3, StatSoft, USA). To determine the significance of differences between the values of variables for male middle-distance runners and long-distance runners, Student's t-test for independent variables was applied. To investigate the nature of the distribution of the results of the Shapiro-Wilk test was conducted. In rejecting the assumptions of normality of the assessment distribution of the significance of diversity, we used the Kruskal-Wallis test. The effect size of the difference between the results of the group with SCH and the healthy group was calculated using the 'Hedges G' formula (small effect: < .5; medium effect: .5 to 0.8; large effect: > .8). Data on fracture frequency, etiology, and localization of fractures were analyzed using the chi-square test. The phi factor (Φ) was used to determine the effect size for the chi-squared test (small effect: .1; medium effect: .3; large effect: .5). ANCOVA analysis of covariance was used to assess the strength of the relationship between hip bone parameters and body compositions, components of the somatotype, number of fractures, sports competition, and training experience. The values of adjusted determination coefficients R^2 were given. We tested the interaction between each covariate and the grouping variable. No significant interactions were found, indicating that the assumption of homogeneity of regression slopes was met. Levene's test was applied to verify equality of error variances across groups, and the results confirmed homogeneity of variances ($P > 0.05$). Variance Inflation Factor (VIF) values for the covariates were all below the commonly accepted threshold of 5, indicating no problematic multicollinearity. A two-way analysis of variance (ANOVA) was conducted to assess the main effects and the interaction between factor A: type of sport and factor B: training experience in relation to femoral neck T-score. The interaction between the type of sport and the number of fractures with T-score FN was also examined. The effect size was calculated as eta-squared ($\eta 2$) (small effect: <.06; medium effect: .06 – .14; large effect: > .14). In all analyses, levels of significance were: *P< .05; **P< .01; ***P< .001 (P - P-value).

Results

The analysis of individual variables in middle-distance and long-distance runners is presented in Table 1. Considering the diversity of somatic values describing runners, a significantly higher body weight (cm) (large effect: 2.303), BMI (kg/cm^2) (large effect: 1.806), LBM (kg) (large effect: .893), FM (kg) (large effect: 1.800), MM (kg) (large effect: 1.267) was observed in the middle-distance runners compared to long-distance runners. Significant differences were also shown in kinanthropometric variables. Men in the middle-distance runners group had significantly higher endomorphy and mesomorphy scores compared to the long-distance runner's group (large effects: .997 and 2.757). However, men in the middle-distance runners group had significantly lower ectomorphy scores compared to the long-distance runners group (large effects: 3.094). Significant differences were also found in bone variables. Middle-distance runners presented higher BMD FN (kg/cm^2) (large effect: 1.354), BMC FN (g) (large effect: 2.957), T-score FN (large effect: 1.609), BMD TR (kg/cm^2) (large effect: 2.725), BMC TR (g) (large effect: 2.334), T-score TR (large effect: 1.536), total sBMD (kg/cm^2) (large effect: .128), total BMC (g) (large effect: 1.835), and total T-Score (large effect: 1.365) compared to long-distance runners. No significant differences were observed between the groups regarding age (years), training experience 9years), body height (cm), and number of fractures (Table 1).

Fractures etiology and distribution of middle and long-distance

Table 1. The biometric, somatic, and bone characteristics of middle and long-distance runners' group.

Variables	Middle-distance runners (n = 18)	Long-distance runners (n = 19)	*t (P)*	*Hegdes' g*
	Mean±SD			
Basic variables				
Age (year)	23.9 ± 3.2	23.4 ± 1.8	.620 (.539)	.202
Training experience (year)	6.6 ± 2.8	7.4 ± 1.84	-.694 (.492)	.229

Kinanthropometric variables				
Body Height (cm)	177.7 ± 3.21	178.5 ± 2.84	-.427 (.672)	.264
Body Weight (kg)	74.0 ± 5.35	68.6 ± 2,52	3.938 (.000)***	1.303
BMI (kg/m^2)	23.4 ± .79	21.6 ± 1.11	5.792 (.000)***	1.860
LBM (kg)	64.7 ± 4.2	61.7 ± 2.3	2.748 (.009)**	.893
FM (kg)	9.2 ± 1.75	6.9 ± .53	5.541 (.000)***	1.800
MM (kg)	29.6 ± 2.14	27.5 ± 1.01	3.938 (.000)***	1.267
Endomorphy (a.u.)	3.19 ± .43	2.76 ± .45	2.943 (.006)**	.977
Mesomorphy (a.u.)	5.47 ± .64	4.19 ± .18	8.346 (.000)***	2.757
Ectomorphy (a.u.)	2.02 ± .19	2.84 ± .32	-9.439 (.000)***	3.094
Bone variables				
BMD FN (g/cm^2)	1.284 ± .208	1.012 ± .194	4.113 (.000)***	1.354
BMC FN (g)	7.027 ± 1.323	3.961 ± .661	9.987 (.000)***	2.957
T-score FN (a.u.)	1.444 ± 1.728	-.720 ± .834	4.891 (.000)***	1.609
BMD TR (g/cm2)	1.100 ± .182	.697 ± .106	8.281 (.000)***	2.725
BMC TR (g)	16.317 ± 2.912	10.876 ±1.587	7.110 (.000)***	2.334
T-score TR (a.u.)	1.583 ± 1.513	-.188 ± .950	4.290 (.000)***	1.536
Total sBMD (g/cm^2)	1.321 ± 1.856	1.109 ± 1.434	3.903 (.000)***	.128
Total BMC (g)	48.460 ± 8.569	34.952 ± 6.003	5.578 (.000)***	1.835
Total T-Score (a.u.)	1.351 ± 1.554	-.292 ± .731	4.152 (.000)***	1.365
Bone fractures (n) (n/per life)	1.06 ± 1.00	1.32 ± 1.34	-.668 (.508)	.219

Note: BMD- bone mineral density; BMC- bone mineral content; FN- femoral neck; TR- trochanter; BMI- body mass index; FM- fat mass; LBM- lean body mass; MM- muscle mass; Hedges' g - measure of effect size; *t* - Student's *t*-test for independent samples; *P* - *P*-value, levels of significance were: **P*< .05, ***P*< .01, ****P*< .001

runners groups are presented in Table 2. Among middle-distance runners, 66.5% suffered a bone fracture during their career, and 41.7% more than once. In the group of long-distance runners, 68.5% suffered a bone fracture injury, of which 53.8% more than once. In both groups, the most common etiology of fracture was bone stress fracture 38.8% among middle-distance runners and 47.4% among long-distance runners. The most common location of fractures in both groups was the tibia and foot. The chi-square test used shows that the location of fractures, their number, and etiology do not differ significantly between groups (*P* >.05) (Table 2).

Relationships (results of ANCOVA analyses) between femoral

Table 2. Fractures etiology and distribution of the middle and long-distance runners' group.

	Middle-distance runners	**Long-distance runners**	X^2 (*P*) *Φ*
	%		
Number of runners with fractures			
All	12 (66.5)	13 (68.5)	1.104 (.575)
With 1 fracture	7 (58.3)	6 (46.2)	.173
With 2 and more fractures	5 (41.7)	7 (53.8)	
Etiology of fractures			
Fall	4 (22.2)	3 (15.8)	.353 (.838)
Bone stress fractures	7 (38.8)	9 (47.4)	.119
Unknown	1 (5.5)	1 (5.3)	
Location of fractures	%		
Tibia (shin bone)	7 (36.9)	7 (26.9)	
Metatarsal	2 (10.5)	6 (23.1)	
Femur	2 (10.5)	.0 (.0)	12.122 (.354) .696
Pelvis	1 (5.3)	.0 (.0)	
Foot	5 (26.3)	7 (26.9)	
Ankle (medial malleolus, tarsal bones)	2 (10.5)	6 (23.1)	

Note Location of fractures - % of all fractures; X^2 - chi-squared test; *Φ* - phi factor; *P* - *P*-value, levels of significance were: **P*< .05, ***P*< .01, ****P*< .001

Table 3. Relationships between femoral (FN) and trochanter (TR) bone parameters and body compositions, components of the somatotype, number of fractures, sports competition, and training experience (results of ANCOVA analyses).

	BMD FN (g/cm²)	**BMC FN (g)**	**T-score FN**	**BMD TR (g/cm²)**	**BMC TR (g)**	**T-score TR (a.u.)**
			F (P) η²			
FM (kg)	.103 (.751) .004	.009 (.987) .000	.063 (.803) .002	.043 (.838) .002	.559 (.461) .020	.645 (.429) .023
MM (kg)	5.521 (.021)* .156	7.486 (.011)* .211	5.298 (.029)* .159	2.454 (.128) .081	7.252 (.012)* .206	4.090 (.053)* .127
Endomorphy (a.u.)	4.977 (.034)* .151	11.095 (.002)** .284	15.414 (.001)*** .355	4.722 (.038)* .144	2.509 (.124) .082	8.433 (.007)** .231
Mesomorphy (a.u.)	0.813 (.375) .028	0.168 (.685) .006	2.406 (.132) .079	4.043 (.054)* .126	0.001 (.982) .000	6.754 (.015)* .194
Ectomorphy (a.u.)	.164 (.689) .006	.489 (.490) .017	.083 (.775) .003	.011 (.916) .000	0.444 (.511) .016	2.657 (.114) .087
Number of fractures (n/per life)	2.718 (.110) .088	.281 (.600) .010	.004 (.948) .000	2.013 (.167) .067	0.903 (.350) .031	.052 (.822) .002
Training experience (years)	.375 (.545) .013	.319 (.577) .011	1.584 (.219) .054	0.419 (.523) .015	0.335 (.567) .012	1.741 (.198) .059
Sports competition (type)	.031 (.861) .001	5.685 (.024)* .169	.016 (.902) .001	3.461 (.073) .110	1.710 (.202) .058	1.664 (.208) .056
F (*P*)	6.65 (.000)***	25.93 (.000)***	14.31 (.000)***	17.11 (.000)***	14.39 (.000)***	10.46 (.000)***
*adj. R*²	.56	.84	.75	.78	.75	.68

Note: BMD – bone mineral density; BMC – bone mineral content; FN – femoral neck; TR – trochanter; F - Ronald A. Fisher's test; *adj. R*² the adjusted *R*-squared values of determination; *η2* - eta-squared, effect size; *P* - *P*-value, levels of significance were: **P*< .05, ***P*< .01, ****P*< .001

(FN) and trochanter (TR) bone parameters and body composition, components of the somatotype, number of fractures, participation in sports competitions, and years of training experience are presented in Table 3. The results of covariance analyses showed that BMD FN (g/cm^2) was significantly influenced by muscle mass (kg) and endomorphy (scores) (*adj.* R^2 = .56). The same effect of these two variables was noted on the T-score FN (*adj.* R^2 = .75). In turn, BMC FN was affected by the type of sports competition, muscle mass (kg), and endomorphy (scores) (*adj.* R^2 = .84). The results of covariance analyses showed that BMD TR (g/cm^2) was significantly influenced by: endomorphy (scores) and mesomorphy (scores) (*adj.* R^2 = .78). BMC TR (g) was significantly affected by muscle mass (kg) (*adj.* R^2 = .75). In turn, T-score TR was influenced by muscle mass (kg), endomorphy (scores), and mesomorphy (scores) (*adj.* R^2 = .68), (Table 3).

A two-way analysis of variance (ANOVA) was conducted to assess the main effects and the interaction in the first model between factor A: type of sport and factor B: training experience with respect to T-score FN, and in the second model between factor A: type of sport and factor B: the number of fractures with respect to T-score FN (Table 4). The two-way analysis of variance revealed statistically significant main effects for both types of sport (F = 44.400, P < .001, η^2 = .589) and years of training experience (F = 12.415, P < .001, η^2 = .445). This indicates that both the type of sport and the duration of training have a significant impact on femoral neck T-score. Moreover, a significant interaction was observed between sport type and training experience (F = 4.863, P = .015, η^2 = .239), suggesting that the effect of one factor (e.g., sport type) on T-score depends on the level of the other factor (i.e., training duration). The η^2 value for the interaction indicates a large effect size (η^2 > .14), emphasizing the importance of the interplay between these two variables. Overall, the model explains a substantial proportion of the variance in femoral neck T-score, as reflected by the high eta-squared (η^2) values across all effects. In the second model, the effects of two factors were evaluated: type of sport (Factor A) and number of fractures during lifetime (Factor B) on femoral neck T-score (T-score FN), as well as their interaction. The effect of sport type (Factor A) was statistically significant (F = 22.232, P < .001) and demonstrated a large effect size (η^2 = .434). This indicates that the type of sport practiced significantly differentiates femoral neck T-score values. The effect of the number of fractures (Factor B) was also statistically significant (F = 8.552, P < .001), with a large effect size (η^2 = .469). This suggests that fracture history has a significant impact on femoral neck T-score. The interaction between sport type and number of fractures (A × B) was not statistically significant (F = 1.158, P = .343, η^2 = .107), indicating that the effect of one factor on T-score FN does not depend on the level of the other. In summary, both sport type and number of fractures have significant and independent effects on femoral neck bone mineral density as measured by T-score. However, no interaction between these factors was observed (Table 4).

Table 4. Two-way ANOVA assessing main effects and interaction of sport type and training experience, as well as sport type and fracture number, on femoral neck T-score.

Model 1 **Source of Variation**	**SS**	**MS**	**F**	***P*-value**	**η2**
Factor A (type of sport)	44.390	44.390	44.400	.000	.589
Factor B (years of training experience)	24.825	12.413	12.415	.000	.445
A x B Interaction	9.723	4.861	4.863	.015	.239
Error	30.993	1.000	-	-	-
Model 2 Source of Variation	*SS*	*MS*	*F*	*P-value*	*η2*
Factor A (type of sport)	23.454	23.451	22.232	.000	.434
Factor B (number of fractures in life)	27.063	9.021	8.552	.000	.469
A × B Interaction	3.664	1.221	1.158	.343	.107
Error	30.590	1.055	-	-	-

Note: *SS* – sum of squares*; MS* – mean square*; F* – F-statistic*; P-value – significance level; η²* – eta squared, effect size

Discussion

A comparative analysis of middle- and long-distance runners revealed significant differences in both somatic and kinanthropometric as well as bone parameters. Middle-distance runners were found to have significantly higher body weight (kg), BMI (kg/m^2), LBM (kg), FM (kg), and MM (kg) compared to long-distance runners, suggesting different physiological demands of these disciplines.[25] Moreover, middle-distance runners exhibited significantly higher values of endomorphy and mesomorphy components, indicating greater body massiveness and higher fat content. In contrast, long-distance runners showed higher ectomorphy components, confirming their leaner body build, likely more advantageous for running economy over longer distances.[26]

Particularly interesting are the results related to bone parameters. Middle-distance runners presented higher BMD (g/cm^2) and BMC (g) values both in the femoral neck and trochanteric regions, as well as higher T-score. These differences suggest that middle-distance training may more effectively stimulate bone remodelling and mineralization due to the greater use of high-load training components. Additionally, numerous publications indicate that athletes with low BMD are particularly those engaged in elite sports where low body mass combined with high training volume is desirable.[27-29] This is a relevant observation in the context of osteoporosis prevention and overall bone health in athletes.

This study also analyzed the frequency and localization of bone

stress fractures. A similarly high incidence of fractures was found in both groups, at 66.5% and 68.5% respectively, with stress fractures being the most common type. These findings align with data presented in the scientific literature on long-distance runners. Fractures were mainly located in the tibia and foot, confirming that the skeletal system of the lower limbs is most vulnerable to injury in middle- and long-distance running.[30]
In a study by Axel Wolff and colleagues, published in 2025 by The American Journal of Sports Medicine, involving 221 long-distance runners (114 women, 107 men), a total of 154 bone stress fractures occurred over 482 years of athletic activity, resulting in an incidence rate of 32 BSF per 100 years of sport. These results highlight the concerning prevalence of this issue, even at the collegiate level.[31]
Bone mineral status is multifactorially determined. In this study, the influence of body composition and somatotype components on femoral bone status was analyzed. Both muscle mass (MM) and the endomorphy component had a significant impact on femoral neck BMD. These results confirm the importance of muscular development and appropriate fat content for bone health. Additionally, femoral neck BMC was also dependent on the type of sport discipline. For the trochanteric bone parameters, endomorphy and mesomorphy components, as well as muscle mass, were significant.
In a study by Pluijm, based on a research group of 522 participants (264 women and 258 men) from the Longitudinal Aging Study Amsterdam, it was demonstrated that FM and MM are strong independent determinants of total hip BMD,[32] a finding also reflected among our tested athletes. The mechanism affecting the positive correlation between MM and BMD is quite well known and described. Greater muscle mass in an athlete generates greater mechanical loads, and this in turn stimulates bone growth processes significantly. The force exerted by muscles during contraction affects bones through mechanotransduction. In this process, osteocytes respond to changes in load, and their activity strengthens bone structure.[33]
The interaction between muscle mass and bone parameters is made possible by two mechanisms, namely mechanical loading and biochemical signalling. Muscle contraction generates forces applied to bone — the greater the force, the stronger the osteogenic stimulus. This aligns with Frost's mechanostat theory, which posits that bones adapt their mass and structure based on mechanical loading. Muscles secrete bioactive proteins (myokines) like myostatin, which directly influence bone metabolism. Sclerostin, mainly produced by osteocytes, acts as an inhibitor of bone formation. Its secretion is modulated by mechanical strain, less mechanical load increases sclerostin, reducing bone formation.[34]
There are many mechanisms responsible for the influence of FM on BMD, and particularly interesting to explore are differences in the nature of the FM vs. BMD interaction in studies of the general population vs. professional athletes. Some studies show a positive effect of higher FM on BMD in young adults, arguing that increased body mass contributes to greater impact during weight-bearing activity. Besides mechanical loading, there is also an indirect positive influence of fat tissue on bone metabolism through hormonal and cytokine activity. [35]
It has been suggested that fat may stimulate bone formation through estrogenic production via aromatization of androgens and through increased insulin and peripheral leptin levels.[36]
On the other hand, some studies indicate a negative correlation between FM and BMD, suggesting that fat may have a detrimental effect on bones due to increased pro-inflammatory cytokines. [37]
We believe that this heterogeneity in findings may be due to differences in metabolic activity between subcutaneous and visceral fat, as recent research suggests that fat distribution and type may differentially affect the correlation with BMD. For athletes who are subjected to regular and systematic training, the effect of adipose tissue on BMD is not always clear-cut and shows the same nature of interaction. The relationship and its nature between adipose tissue and BMD is complex. Many factors can interact unidirectionally with adipose tissue on bone tissue. The effect of adipose tissue on bone tissue varies depending on the type of sport, sport level, and gender. In endurance and strength sports, adipose tissue can have a positive effect on bone health and bone quantitative parameters such as BMD and BMC. This is particularly evident when combined with resistance training. In athletes from different sports, with different energy expenditure and body composition, BMD does not consistently correlate with body fat levels.
The specific sport discipline and the nature of the physical activity often influence this relationship. Our study specifically examined athletes who, despite typically having low levels of fat mass due to high energy expenditure and a predominance of endurance training, still showed significant effects on their BMD.
An important aspect of bone health in sports is the type of training and athletic discipline due to different osteogenic indexes. The results of this study confirmed that other types of running training may differentially affect bone metabolism and fracture risk. Middle-distance runners, due to higher muscle mass and greater mesomorphy, had better bone parameters. This suggests that long-distance runners may benefit from incorporating strength training elements to improve bone mineral density and prevent stress fractures. [38]
Long-distance runners are particularly at risk for stress fractures, which may result from prolonged bone loading without adequate regeneration. Regular, repetitive bone loading in long-distance running, although leading to adaptation in the muscular and cardiovascular systems, may not sufficiently stimulate bones due to too low impact. Therefore, long-distance runners may be more susceptible to bone structure weakening and, consequently, to stress fractures. In view of the risk of low BMD in long-distance runners, it is recommended to include strength training elements in their training plan.
Regular resistance training using various forms of exercise, for example, with weights such as dumbbells or resistance bands, can influence optimal BMD. Incorporating weight-bearing exercises into a training program at the equivalent stage of sports training can be very effective in maintaining bone health. Doing so can reduce or eliminate the risk of injury.
Middle-distance running can have a stronger effect on the skeletal system than other forms of running or endurance training. Their distinctive features, such as moderate intensity, variable pace, and stride length, create a unique loading pattern in the lower extremities, which promotes bone remodeling and increased bone density. [39]
The combination of continuous running and the short recovery periods in middle-distance training promotes a higher frequency of mechanical loading on the bones compared to longer-distance running. The moderate-intensity and repetitive nature of the activity allows for both the mechanical strain and hormonal responses (e.g., the release of growth factors like IGF-1) that are conducive to bone strengthening. [40]
A strong point of the described study is the high athletic level of the participants, who successfully competed at both the European Summer and Indoor Championships. A limitation of the study is

the relatively small sample size and the cross-sectional nature of the observation. It is important to remember the limitations of the bioelectrical impedance method, specifically in athletic populations. Although this method is widely used due to its practicality and non-invasiveness, certain factors such as hydration status and body composition differences in athletes may affect accuracy. The statement about "large effects" for multiple variables should be interpreted cautiously, given the small sample size.

In the limitations of this study, we specifically acknowledge that, despite efforts to ensure sample homogeneity, we did not control for dietary intake, calcium or vitamin D levels, endocrine profiles (e.g., estrogen, testosterone, or IGF-1 concentrations), or detailed individual training histories beyond general categorization by sport type.

These factors may have contributed to BMD variability. It is worth including them in future studies for more comprehensive data collection and analysis. Subsequent study projects expanded to include other groups of athletic competition and other sports could provide valuable information on the dynamics of changes in bone parameters in response to various running and strength training interventions. Another important point for future research is to analyse the effects of diet, calcium, and vitamin D supplementation, and hormonal balance on bone parameters in runners. In summary, the study provides important evidence of differences in body composition and bone parameters between middle- and long-distance runners, suggesting a specific influence of different types of running training on bone metabolism. This has practical implications for training optimization and injury prevention in these sports disciplines.

Practical applications

The use of exercises with a high osteogenic index may positively affect bone tissue quality and serve as an effective tool in fracture prevention. Considering the obtained data, it is worth considering the inclusion of such exercises in the training plans of long-distance runners as a component supporting proper BMD development. In specific training recommendations, in important to use a type of resistance exercise (e.g., jump training, loaded squats). Also to be emphasized are the benefits of plyometric exercises, such as jump training, which generate high mechanical loads that stimulate bone formation, and loaded resistance exercises, such as squats and deadlifts, which exert significant axial compression and shear forces on the skeleton.

For a professional athlete to enjoy a long-term sports career, age- and gender-appropriate bone mineral density is essential. Optimal BMD is crucial not only for the health of athletes but also for the length of their professional sports careers. Therefore, it is reasonable to prepare a plan and incorporate sports practice screening tests that assess bone mineral status.

Early diagnosis as part of primary prevention is important before the underestimated BMD and fractures occur. Hence, endurance athletes should be included in routine bone screening between the ages of 20 and 25, or earlier during peak bone mass development. It is also of particular importance in athletes at risk for low energy availability.

The preferred and recommended method for assessing BMD is dual-energy X-ray absorptiometry (DXA) because of its high accuracy and wide availability. Screening should be performed annually or biennially, depending on the individual risk factors of the athletes being tested, including variables such as underweight, energy deficit, history of childhood rickets, or family history of osteoporosis. Resistance training and plyometric exercises can be effectively integrated into periodic training plans, especially during phases of reduced training load (such as the off-season).

Conclusions

This study demonstrated that the type of athletic training and body tissue composition had a significant impact on BMD in the hip region. The type and specificity of training in middle-distance runners had a more favourable effect on bone parameters compared to long-distance runners. This relationship may be related to the greater mechanical load resulting from greater muscle mass and more intense osteogenic stimuli.

Systematic, long-term, and appropriately intense athletic training can lead to lasting, beneficial changes in bone mineralization and greater mechanical strength. The results of this study emphasize the importance of regular bone health monitoring in track and field athletes. Such bone health diagnostics should be particularly targeted at high-risk groups, such as long-distance runners.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Ethical Committee approval

The study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. The project complies with the principles of bioethics, as confirmed by the Bioethics Committee of the National Institute of Public Health, National Institute of Hygiene in Warsaw, Poland (protocol number 1/2021).

ORCID

Jakub Bałdyka ID https://orcid.org/0009-0009-2509-3294
Anna Kopiczko ID https://orcid.org/0000-0002-1222-113X

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The authors have no conflicts of interest to declare.

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Author-s contribution

Conceptualization, J.B.; methodology, A.K.; software, J.B. and A.K.; formal analysis, J.B.; investigation, J.B.; resources, J.B.; data curation, A.K.; writing—original draft preparation, J.B. and A.K.; writing—review and editing, J.B. and A.K.; supervision, A.K.; project administration, J.B. All authors have read and agreed to the published version of the manuscript.

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Corresponding information:
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Correspondence to: PhD Student Jakub Bałdyka
University: Department of Theory of Sport
Józef Piłsudski University of Physical Education
Marymoncka, 34, 00-968 Warsaw, Poland
E-mail: jakub.baldyka@awf.edu.pl