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Original Investigation

Relationship between bone mineral density and body compositions, strength, type of sport competition, vitamin D and birth-related factors in elite Polish track and field athletes: a cross-sectional study

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Purpose: The purpose of this investigation was to characterize the forearm bone mineral density (BMD) in Elite Competitive Track and Field Athletes. Somatic, body composition, hand grip strength birth variables, and blood vitamin D levels were also analyzed.
Methods: In this cross-sectional study, the participants were 30 elite Polish athletes. Somatic measurements, body composition by kinanthropometry, and bioelectrical impedance were taken. Forearm bone parameters were measured by densitometry in two points distal (dis) and proximal (prox). Measurement of hand grip strength (HGS) on a dynamometer was performed. Birth-related factors such as birth weight and length of breastfeeding were collected by direct interview. Vitamin D concentration was assessed by blood test.
Results: Low BMD was not observed in the distal part of the forearm. Significantly more frequent low BMD prox were found in endurance athletes (EA) group compared to throwing athletes group (TA) ($\chi2=10.8$; $P = .001$; $\Phi = .6$). Inadequate vitamin D levels were significantly higher in the EA group compared to TA ($\chi2=10.8$; $P = .001$; $\Phi = .6$). The main parameters affecting BMD dis and BMC prox of men athletes were HGS (kg) and type of sports competition (R^2 adj= .93; .89). BMC dis was affected by the type of sports competition (R^2 adj= .83). There was also a significant relationship between the T-score prox and the HGS (R^2 adj= .98). In the case of women, the main parameters affecting BMD prox were menarche age and body composition (R^2 adj= .93). The BMC prox was affected by the age of the menarche (R^2 adj= .73).
Conclusions: In conclusion, the present study found that the highest BMD of the forearm bones was characterized by men and women athletes training in athletic throws relative to running sports. Screening assessment of bone mineral status should be included in sports diagnostics.

Keywords: forearm bone mineral density; body composition; vitamin D; hand grip strength; birth weight; length of breastfeeding

Introduction

Bone tissue is a type of connective tissue. It forms a rigid structure made of organic (e.g.: collagen fibers, cells) and inorganic (including calcium, magnesium and phosphorus compounds) components that provide them with strength and resistance to injury. Bone has many important functions in the body, it provides structural support for load bearing and movement serves as a reservoir for minerals such as calcium, phosphorus and magnesium, and houses marrow that produces red blood cells and protects internal organs.[1]
Bones and muscles interact with each other through physical forces. The physical forces exerted on a person are those that arise during movement, exercise, and those that interact through gravity itself. These result in conditions for bone formation and muscle hypertrophy. During the interaction of physical forces, ankle and muscle mass is increased, the resistance to deformation and stiffness of cells and tissues is increased, which directly affects the lower risk of fractures during physical activity.[2-3] The absence of the effects of gravity eliminates stress on bones and results in a significant loss of bone mineral density (BMD), which is further evidence that simply moving under the influence of Earth's gravity appears to be one of the greatest incentives for increasing bone mass.[4]
Another important factor that affects the level of bone mineral density is the load caused by muscle contraction. It affects the local adjustment of bone mineral density in the vicinity of the attachments.[5] These mechanisms help to explain the high mineral density among athletes training in strength sports. Furthermore, several other factors influence the mineral density of athletes, including hormonal factors, diet, dietary supplementation, body type and body tissue composition, general health, and especially diseases affecting bone metabolism.[6]
Training does not always have a positive effect on bone metabolism. This happens when the type of mechanical loading on the bones is inadequate or when other elements affecting bone metabolism such as inadequate calcium supply, vitamin D, too few kcal in the diet, or hormonal disorders are disturbed. There is a large body of literature that indicates that athletes with low BMD are especially those who train in competitive sports where low body weight combined with high training volume is desirable.[6]

Injuries caused by bone stress (BSI) are a relatively common overload symptom in athletes.[7] BSIs are overload injuries associated with repetitive stress on the bones as a result of high amounts of exercise and inadequate recovery periods. BSI signifies the inability of skeletal bones to withstand repetitive loads, leading to structural fatigue and local pain. These injuries are common among runners, athletes, and endurance athletes. BSI varies in severity and initially periosteal and bone marrow swelling is noted. In more severe conditions, there are stress fractures with prominent fracture lines. BSI accounts for up to 10% of all injuries in sports, to up to 30% of injuries among runners.[8-9] In clinical practice, bone mineral density testing is indicated in patients with recurrent fatigue fractures.[9] The systematic diagnosis of bone mineral status can be an effective preventive measure in sports injuries associated with overloading the skeletal system.

The purpose of this investigation was to characterize the bone mineral density (BMD) of the forearm in competitive elite track and field athletes. Somatic and body composition variables, birth-related factors such as birth weight and length of breastfeeding, hand grip strength, and blood vitamin D levels were also analyzed and their impact on bone mineralization.

Methods

Participants

This cross-sectional study involved 30 elite competitive track and field Polish athletes, 15 women aged 23.0±2.5 years, and 15 men aged 22.9±1.4 years. All participants were of the same ethnic origin (Caucasian). Among those surveyed are gold medalists, medalists, finalists, semifinalists and participants of the Olympic Games in Tokyo (2021) and Rio De Janeiro (2016), Medalists of the World Indoor Championships in Birmingham (2018), Medalists of the European Senior Championships in Zurich (2014), Medalists of the World Student Championships in Taipei (2017), Medalists of the European Youth Championships in Bydgoszcz (2017). The athletes were divided into 2 categories according to the type of event declared during the competition: endurance athletes EA (medium and long-distance running: 800m, 1500m, 3000m, cross-country running) and throwing athletes TA (hammer throw, discus, shot put, javelin throw). Using a face-to-face interview with each participant, data was collected on health status, including past injuries and fractures. In addition, data was collected describing the training currently being performed as well as data on past physical activity.The study was carried out on no-training days in the laboratory of densitometry and kinanthropometric tests, and at the Central Center for Sports Medicine in Warsaw. All measurements in this project were carried out by a team of specialists with extensive research experience and the necessary qualifications and licenses. The exclusion criteria recommended for studies of bone conditions were applied to study a homogeneous group. This eliminates several confounding variables such as the impact of metabolic diseases that significantly worsen bone status by their pathomechanism. Exclusion criteria: contraindications to densitometry and bioelectrical impedance testing, the test should not be performed within two days after the administration of a contrast agent (e.g., after a CT scan with contrast), prematurely born, bone, kidney, and thyroid diseases, cancers, rheumatoid arthritis, and long-term steroid treatment. Participants were informed not to take dietary supplements or medications containing calcium on the day before the densitometry test. Following good research practices, written consent was obtained from all study participants to participate in the entire study design. The entire procedure and organization of the study complied with the World Medical Association's Code of Ethics (Declaration of Helsinki) for experiments involving human subjects. In addition, a positive opinion on the quality of the project was obtained from the Senate Committee on Research Ethics of the Józef Piłsudski Academy of Physical Education in Warsaw (SKE 01-09/2017).

Kinanthropometric measurements & bioelectrical impedance methods

The measurements were taken by a kinanthropometry expert according to the standards proposed by the International Society for the Advancement of Kinanthropometry (ISAK).[11] Body height (in cm) was measured in Frankfurt's standing posture. The measurement was made using an anthropometer model GPM Anthropometer, manufactured in Switzerland. The accuracy of the measurement was 1 mm. Measurements included: elbow width, wrist width, and forearm length (in cm, with the GPM Large and Small Spreading Calliper, Switzerland).

Body composition was analyzed by bioelectrical impedance method (BIA). The In Body type 270 Body Composition Analyzer was used with fat-freebies about 20, 100 kHz. BIA was performed in standardized conditions: ambient temperature between 23–25 °C, fast for >3 h, empty bladder. Measurements included: body mass (in kg), body fat (PBF in %), fat mass (FM in kg), and fat-free mass (FFM in kg).

Dual-energy X-ray absorptiometry

Bone mineral density (BMD in g/cm^2), and bone mass content (BMC in g) in the non-dominant forearm (radius+ulna) were measured using the dual-energy X-ray absorptiometry method. Measurements were made on a Norland model pDEXA instrument. Technical Specifications: scan sites- left and right forearm, scan time: 5 minutes, scanning area: 150 mm by 125 mm, resolution: 1 mm by 1 mm, X-ray source: tin filtered 60 kV, X-ray energies: 28 keV and 48 keV, exposure: < 0.2 mRems. The densitometer model used has a safe effective dose of 0.05. Using large anthropometric calipers, the length of the non-dominant forearm was measured. The measurement was made at the radial-elbow (r-sty) points. According to the densitometry method, two measurement points were scanned: the first at the proximal and the second at the distal part of the bone. Regression statistics were reported for all similar areas of interest (ROIs). The distal ROIs span 10mm of the lowest BMD region in the distal forearm and are found using an automated search routine. The proximal site spans 10mm starting at the ⅓ forearm length and continuing proximally.[12-13]

Birth Factors

During the face-to-face interviews, information was taken about the infant's birth weight (BW in grams) and the length of breastfeeding (in months) by the mother. The athletes completed this data after consulting with their mother or legal guardian. The study included athletes who, according to their mothers' interviews, were assessed as healthy full-term newborns, born between the 38th and 42nd week of pregnancy. Birth weight classifications were adopted according to the recommendation of World Health Organization (WHO) experts where low birth weight was < 2500 grams, very low birth weight <1500 grams, and extremely low birth weight <1000 grams.[14] According to the neonatology recommendation, newborns who weigh more than the usual number of weeks of gestation are classified as large for gestational age (LGA). On the other hand, large babies were classified when they weighed more than 9 out of 10 babies (90th percentile) The length of breastfeeding was assessed according to the Global Public Health Recommendation criteria recommended by the WHO.[15]

Hand grip test

Hand grip strength (HGS) was measured using a Jamar-type hydraulic dynamometer. The measurement was performed on the same limb scanned by densitometry. The Jamar measures HGS through a sealed hydraulic system and displays grip force in pounds and kilograms up to 200 pounds or 90 kg. The procedure was performed seated, the upper arm was with the elbow 90° flexed. The measurement was made on the second handle, which is the standard position recommended by the American Society of Hand Therapists (ASHT).[16] Participants performed three trials. The best result was taken for analysis.

Vitamin D levels

Vitamin D and its active metabolite were assessed based on 25-Hydroxy Vitamin D (25-OH-D) was determined in venous blood. Concentration levels were marked according to medical procedures. Blood was collected in the morning, on an empty stomach, and determined by the CLIA method on a Liaison analyzer. The study was conducted at the Central Sports Medicine Center in Warsaw by qualified medical personnel. Serum 25-Hydroxy Vitamin D_3 (25-OH-D) measurement is usually performed to evaluate the Vitamin D_3 level of individuals. According to the Endocrine Society, 25-OH-D=>30 ng/ml is considered sufficient; 20–29 ng/ml is evaluated to be inadequate, and<20 ng/ml is regarded as deficient Vitamin D status.[17]

Statistical analysis

The research results were analyzed with the use of Statistica software (v.11, Stat. Soft. USA). Means and standard deviations were calculated for each somatic, body composition, strength, biochemistry, bone, and birth variables. Student's t-test for independent variables was used to determine the significance of differences between the values of variables for endurance and throwing athletes. The size of the difference between the results of the EA and TA group was calculated using the 'Hedges G' formula (small effect: < .5; medium effect: .5–.8; large effect: > .8). Chi-square was used to test the significance of two types of competition: endurance athletes (EA) and throwing athletes (TA) in the incidence of low BMD, low birth weight, not recommended length of breastfeeding, and deficiency of vitamin D_3 metabolite 25(OH). 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 selected variables and the state of bone mineralization. The values of adjusted determination coefficients R^2 were given. In all analyses, levels of significance were: **P*< .05; ***P*< .01; ****P*< .001 (*P* - *P*-value).

Results

The analysis of individual variables in athletes is presented in Table 1. Considering the diversity of values describing men, a significantly higher body mass (large effect: 2.31), wrist width (large effect: 2.33), elbow width (large effect: 1.14), % PBF (large effect: 2.39), FM (large effect: 2.62), and FFM (large effect: 1.71) was observed in the TA group compared to EA. Among men in the TA group, all analyzed bone parameters were significantly higher compared to the EA group (large effects: 1.22-2.79). Also, men in the TA group had significantly higher serum vitamin D levels compared to the EA group (large effect: 3.18). The analysis of individual variables in women athletes is presented also in Table 1. A significantly higher age (large effect: 1.83), body mass (large effect: 2.44), wrist width (large effect: 3.60), % PBF (large effect: 3.35), FM (large effect: 3.21), FFM (large effect: 1.77) and HGS (large effect: 4.62) was observed in the TA group compared to EA. Among women in the TA group, similar to men, all analyzed bone parameters were significantly higher compared to the EA group (large effects: 2.59-7.17). Also, women in the TA group had significantly higher serum vitamin D levels (large effect: 3.27) and length of feeding by the mother (large effect: 2.39) compared to the EA group (Table 1).

Table 2 shows the prevalence of low BMD (osteopenia), low birth weight, not recommended length of breastfeeding, and deficiency of vitamin D_3 metabolite 25(OH) according to the type of competition: endurance athletes (EA) and throwing athletes (TA). No low BMD was noted in the distal forearm in either the EA or TA group. In the EA group, significantly more frequent low bone density was found in the proximal part of the forearm compared to TA ($\chi2$ = 10.8; *P*= .001; Φ = .6; large effect). Inadequate vitamin D levels (Table 2) were significantly more frequent by more than five times in the EA group compared to TA ($\chi2$ = 10.8; *P*= .001; Φ = .6; large effect).

Relationships (results of ANCOVA analyses) between bone parameters separately for distal (dis) and proximal (prox) segments of forearm and body compositions, strength (HGS), biochemistry, birth variables, and sports competition in athletes are presented in Table 3. The results of covariance analyses between BMD and selected parameters in men showed that distal BMD was influenced by: HGS (kg) and the type of sports discipline practiced (adj. R^2 = 0.93). The same effect of these two variables was noted on the BMC prox (R^2 adj.= .89) In turn, BMC in the distal part was affected by the type of sports competition (R^2 adj.= .83). There was also a significant relationship between T-score prox. and HGS (R^2 adj.= .98).

Relationships (results of ANCOVA analyses) between bone parameters separately for dis and prox segments of forearm and age, age of menarche, body compositions, strength (HGS), biochemistry, birth variables and sports competition in women athletes are presented in Table 3. The results of the covariance analyses between BMD and selected parameters in women showed that BMD prox was influenced by menarche age and body composition such as FM and FFM (R^2 adj.= .93). The same effect of these two variables was noted on the T-score prox (R^2 adj.= .95). In turn, BMC prox (Table 3) was affected by the menarche age (R^2 adj.= .73).

Discussion

The present study found that the highest BMD of the forearm bones was characterized by athletes training in athletic throws relative to running sports. Among men, BMD and BMC of forearm bones were strongly determined by HGS and the type of sports played. In contrast, among women, the main factors influencing BMD and BMC were the age of first menarche and body composition, particularly FM and FFM.

Considering the training load, throwing athletes puts much more stress on the upper extremities. The results confirm the positive effect of training on bone metabolism through its load caused by muscle contraction, leading to local adaptations.[18]

Numerous studies have shown that biological developmental characteristics in women such as age of menarche and associated hormonal changes affect BMD levels in various skeletal locations such as the forearm[19], hip,[20] lumbar spine.[21] It has also been proven that menstrual disorders affect the risk of reduced BMD in exercising women.[22-23]

Our results are consistent with previous studies in terms of the correlation of FM% and FFM with BMD among women. In a study conducted by Wang et al. on an ethnically diverse sample of 900 young women aged 20-25, it was observed that fat-free

Table 1. Means and standard deviations of variables in the groups of endurance athletes (EA) and throwing athletes (TA n) as well as the significance of differences between the means (Student's *t*-test, *P*)

	Men (n=15)				Women (n=15)			
Variables	**EA (n=8) Mean ± SD**	**TA (n=7) Mean ± SD**	***t (P)***	***Hegdes' g***	**EA (n=8) Mean ± SD**	**TA (n=7) Mean ± SD**	***t (P)***	***Hegdes' g***
Age (years)	21.1±1.2	21.2±1.7	-0.166 (.871)	.00	19.4± .9	21.6±1.5	-3.537 (.004)**	1.83
Menarche age (years)	-	-	-	-	15.4±2.5	16.0± .6	-0.585 (.568)	.39
Training experience (years)	8.2±1.5	9.1±1.7	-1.027 (.323)	.56	8.8±2.5	9.4±1.8	-1.027 (.323)	.28
Body height (cm)	183.9±6.7	180.2±8.8	0.867 (.402)	.48	173.0±5.0	170.2±2.4	1.322 (.209)	.757
Body mass (kg)	71.5±7.9	92.3±10.1	-4.220 (.001)**	2.31	58.1±4.7	75.8±9.8	-4.559 (.001)***	2.44
Forearm length (cm)	28.3±1.9	29.0±1.1	-0.936 (.366)	.48	25.9±8.6	26.0±10.3	-.224 (.826)	.01
Wrist width (cm)	5.7± .2	6.4± .4	-3.733 (.003)**	2.33	5.0± .3	5.9± .2	-6.475 (.000)***	3.60
Elbow width (cm)	6.9± .4	7.3± .3	-2.664 (.019)*	1.14	6.2± .3	6.4± .4	-1.152 (.270)	.57
PBF (%)	7.5±1.9	15.5±4.8	-3.834 (.002)**	2.39	13.0±2.9	21.1±2.0	-6.171 (.000)***	3.35
FM (kg)	5.4±1.4	14.7±5.7	-3.872 (.002)**	2.62	7.6±2.0	16.1±3.3	-6.194 (.000)***	3.21
FFM (kg)	66.2±7.6	77.6±5.7	-3.336 (.005)**	1.71	50.5±3.7	59.7±6.7	-3.343 (.005)**	1.77
HGS (kg)	116.6±26.6	132.2±13.5	-1.507 (.156)	.78	63.1±8.0	92.9±4.9	-8.529 (.000)**	4.62
BMD dis. R+U	.436± .04	.575± .06	-4.848 (.000)***	2.78	0.354± .04	0.605± .03	-13.864 (.000)**	7.17
BMC dis. R+U	2.023± .21	2.290± .15	-2.805 (.015)*	1.48	1.385± .18	1.734± .09	-4.609 (.000)**	2.59

T-score dis. R+U	-.203± .62	1.108± .63	-3.972 (.002)**	2.10	.070± .64	3.187± .59	-9.794 (.000)**	5.07
BMD prox. R+U	.861± .07	.922± .03	-2.218 (.045)*	1.22	.716± .06	.849± .04	-4.989 (.000)**	2.66
BMC prox. R+U	2.547± .31	2.954± .17	-3.264 (.006)**	1.70	1.850± .12	2.104± .07	-4.800 (.000)**	2.67
T-score prox. R+U	-1.457± .79	.580±1.09	-3.889 (.001)***	2.17	-1.554±0.85	1.021± .49	-7.009 (.000)**	3.84
Birth weight (g)	3550.0±193.5	3890.0±641.0	-1.247 (.234)	.81	2995.0±765.7	3671.4±438.6	-2.055 (.061)	1.12
Length of breastfeeding (months)	9.7±15.4	12.8±9.1	-0.494 (.629)	.25	3.8±2.7	18.0±9.2	-4.212 (.001)**	2.39
25 (OH) D (ng/ml)	35.9±8.8	58.3±5.3	-5.349 (.000)***	3.18	34.0±13.2	58.7±1.9	-4.917 (.000)**	3.27

Note. PBF- body fat in %; FM- fat mass; FFM- fat-free mass; HGS- hand grip strength; BMD-bone mineral density; BMC- bone mineral content; dis.- distal, prox.- proximal; R+U - radius+ulna; EA- endurance athletes; TA- throwing athletes; *P*—p-value, level of statistical significance: **P*≤ .05, ***P*≤ .01 and ****P*≤ .001

Table 2. Assessment of the incidence of low BMD (osteopenia), low birth weight, not recommended length of breastfeeding and deficiency of vitamin D_3 metabolite 25(OH) (results of Chi-square test)

Variables	EA Mean ± SD %	TA Mean ± SD %	χ2 (*P*) Φ
T-score dis.			
Low- osteopenia	0	0	.000 (.000)
Norm	100	100	.0
T-score prox.			
Low- osteopenia	71.4	12.5	10.803 (.001)***
Norm	28.6	87.5	.6
Birth weight			
Large for gestational age	0	12.5	
Norm	85.8	87.5	4.038 (.257)
Low	7.1	0	.4
Very low	7.1	0	
Extremely low	0	0	
Length of breastfeeding			
Too short	50.0	31.3	1.093 (.295)
Recommended	50.0	68.7	.2
25 (OH) D (ng/ml)			
Deficient	0	0	
Inadequate	71.4	12.5	10.803 (.001)***
Sufficient	28.6	87.5	.6

Note. T-score dis. – T-score distal; T-score prox. - T-score proximal; p - p-value, level of statistical significance. *P*—p-value, level of statistical significance: *$P \leq .05$, **$P \leq .01$ and ***$P \leq .001$

mass and fat mass consistently showed a significant positive association with BMD at all skeletal sites.[24]

There are many studies on the mechanisms by which FFM increases BMD. High FFM has a significant effect on relative strength, plus more muscle mass means more forces acting on the bones during movements leading to higher BMD. Moreover, increased FFM most often results from increased physical activity and is the result of a healthy diet that promotes strong bones. FM% through axial loading on the skeleton also affects bone formation. However, the effect of fat mass is not as great on BMD compared to FFM. Moreover, increased fat mass, especially in the visceral region, increases the risk of cardiometabolic conditions.[24-25] Cross-sectional studies show that in power sports, higher lean body mass has a beneficial effect on power and strength generation tasks.[25] In men, the type of discipline strongly conditioned BMD at both forearm locations. This confirms the results that throwing is included in the group of osteogenic exercises causes better mineralization of the forearm bone than running where the forces on the radial and ulnar bones are lower. This is related to the type of osteogenic stimuli present. One of them is mechanical stimuli, that is, forces exerted by contracting muscles (joint force reaction - JFR) and forces associated with the action of gravity (ground force reaction - GFR). The strongest osteogenic effect was observed after exercise of moderate to high intensity, in which both GFR and JFR forces act. These include such forms of exercise as running, jumping, throwing, resistance exercises, dancing, and aerobics. In addition, a greater effect is obtained when dynamic exercises are used. In the methodology of throwing competitions, there are more arm and forearm exercise, supports that is, exercises with a high osteogenic effect. This is a factor that significantly affects GFR and JFR.[26]

Athletic training in throwing also has an impact on HGS. Hand grip strength is a measure of physical capacity frequently used in the screening. This simple measure is associated significantly with both upper and lower body strength.[27] In a systematic review and meta-analysis, the authors also confirmed that muscle strength should be considered a useful marker of skeletal health in young adults and a target outcome for interventions aimed at improving bone health.[28]

However, the relationship between non-adherent muscle strength and bone mineral density is unclear.[29] The effects of grip strength on femoral neck and lumbar spine mineral density were assessed in the general US population. Results from the National Health and Nutrition Examination Survey (NHANES) show that grip strength may be associated with BMD of nonattached bones. Additionally, it has been shown that the grip strength of the dominant hand can be an indicator of BMD in the general US population, regardless of gender and menopausal status.[29]

In this study among men, BMD and BMC of forearm bones were strongly determined by HGS. This confirms that strength exercises that affect hand strength also correlate with better BMD of the forearm.

Health is a fundamental aspect for athletes at any level. An athlete's health is critical to his or her athletic performance, physical performance, and long-term sports career. Adequate bone health ensures an athlete's ability to participate in high-intensity training, competition, and post-exercise recovery. Studies have shown that an athlete with higher bone mineral density is more likely to avoid injury and recover more quickly

Table 3. Relationships between bone parameters and body compositions, strength, vitamin D and birth variables, sports competition (results of ANCOVA analyses)

Variables		BMD dis. (g/cm²)	BMD prox. (g/cm²)	BMC dis. (g)	BMC prox. (g)	T-score dis.	T-score prox.
		F (P)	*F (P)*	*F (P)*	*F (P)*	*F (P)*	*F (P)*
Men							
FFM (kg)		.093 (.776)	1.669 (.266)	.213 (.668)	.063 (.850)	.334 (.594)	3.571 (.132)
HGS (kg)		6.565 (.011)**	3.703 (.127)	3.508 (.134)	7.926 (.048)*	.026 (.879)	7.721 (.021)*
25 (OH) D (ng/ml)		.081 (.790)	1.030 (.368)	3.059 (.155)	.075 (.798)	.125 (.742)	2.369 (.199)
Birth weight (g)		2.966 (.160)	.957 (.383)	.602 (.481)	.492 (.522)	.382 (.570)	.113 (.754)
Length of breastfed exclusively (months)		.893 (.398)	.770 (.430)	.410 (.557)	.006 (.942)	.021 (.892)	3.283 (.144)
Competition (type)		16.430 (.015)*	2.538 (.186)	6.916 (.054)*	7.377 (.007)**	.600 (.482)	59.19 (.001)
	F (*P*)	22.5 (.005)	9.43 (.024)	3.51 (.122)	15.77 (.009)	2.92 (.159)	86.93 (.000)
	R^2 adj.	.93	.83	.60	.89	.53	.98
Women							
Age (years)		.015 (.911)	1.137 (.365)	.035 (.863)	.277 (.635)	1.363 (.327)	.526 (.521)
Menarche age (years)		2.433 (.217)	28.43 (.013)**	.256 (.648)	7.586 (.051)*	1.404 (.321)	33.061 (.011)**
FM (kg)		2.271 (.229)	22.155 (.018)*	.312 (.616)	3.795 (.147)	1.298 (.337)	23.692 (.017)**
FFM (kg)		1.411 (.320)	20.123 (.021)*	.032 (.870)	1.041 (.383)	1.044 (.382)	15.640 (.029)**
HGS (kg)		.189 (.693)	1.496 (.309)	.079 (.797)	1.434 (.317)	.004 (.956)	2.207 (.234)
25 (OH) D (ng/ml)		.000 (.988)	1.991 (.254)	.000 (.995)	.845 (.426)	.007 (.941)	3.449 (.160)
Birth weight (g)		1.289 (.339)	5.833 (.095)	.131 (.741)	.199 (.686)	1.051 (.381)	.135 (.737)
Length breastfed exclusively (months)		.353 (.594)	4.122 (.135)	.053 (.832)	2.329 (.224)	.585 (.500)	4.526 (.123)
Competition (type)		.027 (.880)	5.890 (.094)	.126 (.746)	2.602 (.205)	.058 (.826)	7.031 (.034)*
	F (*P*)	18.65 (.017)	18.40 (.018)	1.73 (.357)	4.69 (.115)	9.19 (.047)	29.21 (.009)
	R^2 adj.	.92	.93	.35	.73	.86	.95

Note. BMD- bone mineral density; BMC- bone mineral content; dis—distal; prox—proximal; FFM—fat-free mass; HGS- hand grip strength; F—Ronald A. Fisher's test; R^2 adj.—the adjusted R-squared values of determination; *P*—p-value, level of statistical significance: *$P\leq .05$, **$P\leq .01$ and ***$P\leq .001$

from potential injuries.[30-31] The study showed that bone stress injuries at anatomic sites with greater trabecular composition in athletes were significantly dependent on low bone mineral density.[6] Regular physical activity is an important factor for health at all ages, including bone health.[30-33]

Practical Applications

Test results are important in the diagnosis of an athlete's health status. The skeletal system plays a significant role in body posture stabilization. It is the structure on which muscles and ligaments rest. Good bone mineral density is the basis for the mechanical strength of the bones to withstand the loads generated in sports training. Diagnostics of bone mineralization of athletes is useful for coaches and athletes because it gives important information about bone health, and assesses whether there is a risk of fractures when BMD is underestimated. One limitation of the study is the small sample size, which sets plans for further studies of bone mineralization assessment of athletes.

Conclusions

In this study indicated that the highest BMD of the forearm bones was characterized by men and women elite athletes training in athletic throws relative to running sports. Taking into account the training load, throwing athletes puts much more stress on the upper extremities. The results confirm the positive effect of training on bone metabolism through its load caused by muscle contraction, leading to local adaptations. Considering professional sports with long specialized training, one can talk about the long-term effect of exercise on bone mineralization.

Among men, BMD and BMC of forearm bones were strongly determined by HGS and the type of sports played, which confirms the effect of training on grip strength and this correlates with forearm BMD. In contrast, among women, the main factors influencing BMD and BMC were the age of first menarche and body composition, particularly FM and FFM, which points to multifactorial determinants of bone mineralization.

Training based on exercises with a high osteogenic index has a positive effect on the good quality of bone tissue. The results of this study suggest that it is worth considering incorporating throwing exercises into other disciplines as an important part of developing good BMD. Age- and gender-appropriate bone mineral density is important for the health of athletes and the proper progression of athletic careers. It is worth considering whether screening for bone mineral status should be included in sports diagnostics. Studying has some limitations. A limitation of the study is the analysis of BMD and its determinants in a cross-sectional study. A study based on baseline measurements of BMD and its changes after a year or two of athletic training would be worthwhile. Another limitation is the relatively small number of athletes. The study should be repeated in the future to extend to a large sample of athletes in various age categories. It is also worth extending the research in the future to include the analysis of more factors affecting bone health, such as diets and eating habits, diet supplementation.

The strengths of the study are the use of recommended test methods, the conduct of tests by qualified specialists, and the execution of tests according to a uniform test protocol for assessing bone mineralization. The exclusion criteria used in the study allowed for the elimination of confounding factors such as metabolic diseases affecting bone deterioration.

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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 was approved by the Senate Ethics Committee for Scientific Research of the Józef Piłsudski University of Physical Education in Warsaw, protocol number SKE 01–09/2017.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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Author-s contribution

Conceptualization, J.B. and A.K.; methodology, A.K.; software, J.B. and A.K.; formal analysis, J.B. and A.K.; investigation, J.B. and A.K.; resources, J.B. and A.K.; data curation, J.B. and 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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