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Bone mineral density and bone stress fractures in high-level endurance runners and combat sports: a cross-sectional study

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Dictionary:

Bone mineral density (BMD) — an indicator of bone strength expressed in grams per square centimetre (g/cm²). It reflects the amount of mineral content within a specific bone area and is commonly used to diagnose osteoporosis and assess fracture risk [14,16]

Bone mineral content (BMC) — the total amount of mineral (in grams) contained within the measured bone region. It represents the absolute quantity of bone mineral matter independent of bone size[14,16]

Dual-energy X-ray absorptiometry (DXA) — a precise and widely used imaging method for assessing BMD and BMC [14, 16]

Bone stress fractures (BSF) — overuse injuries of the bone resulting from repetitive mechanical loading that exceeds the bone's capacity for remodeling and repair. They commonly occur in athletes and military recruits and are associated with low bone mineral density, inadequate recovery, or training errors [6,7]

Abstract:

Background and Study Aim: Combat sports and endurance training significantly affect bone mineral density (BMD), although to varying degrees. Bone stress fractures (BSF) are a relatively recent and not yet fully understood issue in professional athletes. Research has not yet fully resolved the problem of BSF and low BMD, depending on the type of sport. This study aims to identify BMD in the hip and lumbar spine, as well as the incidence of BSF in adult Polish professional long-distance runners and combat sports athletes.

Material and Methods: The study included 60 endurance sports (cross-country running, half marathon, marathon, ultra running,) and 69 combat sports (Brazilian jiu-jitsu, judo, wrestling). The following research methods were used: densitometry, kinanthropometry, bioelectrical impedance, and standardized injury questionnaires.

Results: Individuals practicing in the endurance runners group had significantly lower all bone indicators compared to the combat sports athletes (large effects: >0.8), and significantly higher number of BSF in life (medium effect: 0.5 to 0.8). Femoral neck and lumbar spine BMD below the expected range for age was observed only in endurance sports. A significantly higher percentage of athletes without BSF was recorded in the combat sports group. The results of covariance analyses showed that BMD in the femoral neck was significantly influenced by muscle mass, number of BSF, and sport types (adj. $R^2 = 0.731$). Bone mass was affected by the body height and type of sports (adj. $R^2 = 0.393$). Z-score was influenced by the number of BSF and sport type (adj. $R^2 = 0.722$). All analysed bone indicators in the lumbar spine were significantly influenced by muscle mass and the type of sport.

Conclusions: In this study, there was a large and strong relationship between history of bone stress fracture, sport type, and bone mineral status. A significant fracture and sport type interaction was observed. This suggests that the effect of fracture on the femoral Z-score varies across sport types. Recommendations based on systematic diagnosis of bone mineral status can effectively prevent stress fractures in sports.

Keywords: bone fractures, bone mineral status, Brazilian jiu-jitsu, half marathon, judo, marathon, ultra running, cross-country running, wrestling

1. Introduction

Hand-to-hand combat (fight) systems – a universal name for all systems traditionally associated with 'martial arts', however, when used in scientific publications it means that the author(s) does not promote the pathology of MMM, i.e. bloody neo-gladiatorship, camouflaged under the attractive name of mixed martial arts [49-51].

Neo-gladiator – a person who trains mix martial arts (MMA) and similar forms of hand-to-hand fighting that do not meet the definition of sport according to the Olympic Charter [49].

Bone Mineral Density (BMD) is a measure of the amount of minerals, mainly calcium and phosphorus, contained in bone tissue. It is a key indicator of bone strength and resistance to fractures. It is extremely important in sports, as high mineral density allows for better tolerance of training loads, protects against injuries, and supports the overall efficiency of the musculoskeletal system. Low bone density, on the other hand, can lead to osteopenia or osteoporosis, increasing the risk of overload injuries. Regular strength training and a diet rich in calcium, vitamin D, and protein help maintain or increase bone mineral density, which is especially important for athletes of all ages [1, 2]. However, every sport involves increased stress, and prolonged and intense training can lead to overload of the musculoskeletal system and injuries. These can occur randomly or be specific to a particular sport. One of the challenges in analysing injuries is the variety of definitions of injury and its severity [3-5].

Among stress injuries, bone stress fractures (BSF) are of particular clinical significance. They constitute a significant health problem in the athletic population, accounting for 1% to 20% of cases reported in sports medicine clinics and approximately 10% of all orthopedic injuries [6, 7].

The incidence of these injuries is estimated at 1.54 per 100,000 athlete exposures. Epidemiological data indicate that women suffer injuries more often than men, and one in seven athletes has a history of stress fractures. In gender-comparable sports, the incidence of BSF is 2.22/100.000 in girls and 1.27/100.000 in boys. The highest incidence of SF is observed in long-distance runners, track and field athletes, and dancers, where they account for 15-20% of all musculoskeletal injuries. BSF most commonly affects the tibia (83%), tarsal bones (10%), metatarsals (5%), and femur (2%), although they can occur in virtually any bone, including the bones of the upper limbs, ribs, and vertebral arches [6-8].

The presumed pathophysiology of BSF is an imbalance between bone formation and resorption processes, leading to the accumulation of microdamage resulting from repetitive mechanical stress. In athletes with bone metabolism disorders, even relatively small loads can exceed the tolerance threshold of bone tissue, initiating an overload process. The extent of microtrauma depends on the magnitude, frequency, duration, and direction of the load, as well as the individual biological properties of the bone [9, 7, 8].

Despite growing interest in bone health in various sports disciplines, direct comparative studies analysing BMD and the incidence of BSF between high-level endurance runners and combat sports athletes remain scarce. Most studies to date have focused on single sports populations or have used small, heterogeneous study samples [10, 11]. Such comparative analyses are crucial for clarifying the relative contribution of mechanical loading patterns, training characteristics, body composition, and nutritional practices to skeletal health. The dichotomy between repetitive, submaximal axial loading in endurance running and high-magnitude multidirectional forces in combat sports provides a unique opportunity to examine how different mechanical environments influence bone adaptation and injury risk.

This study aims to identify BMD in the hip and lumbar spine, as well as the incidence of BSF in adult Polish professional long-distance runners and combat sports athletes.

Therefore, this study hypothesized that (1) combat sports athletes have significantly higher BMD compared to endurance runners, (2) endurance runners have a higher incidence of BSF, especially in the lower limbs, and (3) BMD distribution is specific to the sport discipline, runners show increased mineralization in the lower limbs with reduced BMD in the lumbar spine, while combat sports athletes show a more even distribution resulting from multidirectional loading of the skeleton.

2. Materials and Methods

Participants

The study sample size was 129 male professional Polish athletes: 60 endurance sports (marathon, half marathon, ultra running, cross-country running), aged 23.9 ±1.5 years with training experience of 7.7 ±1.8 years, and 69 combat sports (Brazilian jiu-jitsu, judo, wrestling), aged 23.4 ±1.8 years with training experience of 7.4 ±1.8 years. All examined athletes belonged to the Caucasian ethnic group. Among the men training for long-distance running were leading competitors, medallists, and record holders in marathons and ultramarathons, as well as participants in prestigious international championships, including participants in the New York Marathon, the Berlin Marathon, the Pieniny Ultra-Trail, and the Ultra-Trail du Mont-Blanc.

Among combat sports athletes, key athletes from Warsaw combat sports clubs and participants in international and national championships were examined. All of the participants were informed in writing about the aims, benefits, and procedure of the research project, and about the possibility of withdrawing from the study at any moment. The exclusion criteria were contraindications for the basic kinanthropometric measurements, densitometry scan, and metabolic diseases that secondarily disrupt bone metabolism as thyroid diseases, Hashimoto, rheumatoid diseases, and rickets.

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 2/2025), and the study was conducted according to the rules and regulations of the Declaration of Helsinki for experiments involving humans [12].

Kinanthropometric measurements

Kinanthropometric measurements were performed in accordance with the standardized protocols of the International Society for the Advancement of Kinanthropometry [13]. Certified anthropometrics conducted all assessments with more than 15 years of professional experience. Body weight (kg), fat mass (FM, kg), lean body mass (LBM, kg), and muscle mass (MM, kg) were assessed using the bioelectrical impedance analysis (BIA) method. Measurements were carried out in the morning, under fasting conditions, with participants barefoot and wearing no clothing, using the Javon Medical Body Composition Analyzer, model X-SCAN PLUS II (Jawon Medical, Korea; Certificate No. EC0197 for medical devices). The device operates within a measurement range of 100–950 Ω and has a precision of 0.1 kg. Body height (cm) was measured with a stadiometer (Seca 264, Seca GmbH & Co. KG, Hamburg, Germany) equipped with Seca 360° wireless technology, a heel positioner, and a Frankfurt plane head positioner, providing a precision of 0.1 cm. Height measurements were obtained in the morning, with participants standing barefoot.

Methods for assessing bone indicators

Bone mineral density (BMD, g/cm²), bone mineral content (BMC, g), and Z-scores of the lumbar spine (L1-L4), and also nondominant hip, including the femoral neck and trochanter, were assessed using dual-energy X-ray absorptiometry (DXA). All measurements were performed with a Norland XR-46 bone densitometer (Swissray-USA, Norland Medical Systems, Madison, WI, USA). Data analysis was based on Z-scores, which represent the number of standard deviations by which an individual's BMD differs from the mean value of an age-, sex-, and ethnicity-matched reference population [14, 15]. In accordance with the 2023 updated official positions of the International Society for Clinical Densitometry [16]. Z-scores rather than T-scores are recommended for BMD reporting in premenopausal women and men younger than 50 years. A Z-score of ≤–2.0 is defined as below the expected range for age, whereas a Z-score above –2.0 is considered within the expected range for age [16].

The precision error, expressed as the coefficient of variation, was less than 1% during the study period. DXA scans (total and sub regional) were obtained for all participants and performed by certified radiology technicians [17]. In accordance with the densitometric testing procedures and the recommendations of the International Society for Clinical Densitometry [16], the scanner was calibrated daily. Calibration was performed against the standard phantom block provided by the manufacturer to control for potential baseline drift.

Clinical assessment of bone stress fractures

In the first stage, clinical methods were applied to identify the occurrence of bone stress fractures. Each participant completed standardized injury questionnaires, including the Oslo Sports Trauma Research Center Overuse Injury Questionnaire [18], and training diaries were reviewed to record the incidence and characteristics of musculoskeletal complaints. A sports physician also conducted a structured medical interview to obtain detailed information regarding injury history, training load, and potential risk factors. In addition, a retrospective review of medical records was performed to verify self-reported data and to identify previous bone stress fractures or related musculoskeletal injuries documented over the past competitive seasons. This combined approach allowed for the comprehensive assessment of both current and past bone stress fracture incidence among the athletes.

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 particular variables for male endurance sports and combat sports, 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 was calculated using the 'Hedges G' formula (small effect: <0.5; medium effect: 0.5–0.8; large effect: >0.8). Data on the mineralization status of bone, bone stress fracture frequency, and localization of fractures were analysed using the chi-square test. The phi factor (Φ) was used to determine the effect size for the chi-squared test (small effect: 0.1; medium effect: 0.3; large effect: 0.5). ANCOVA analysis of covariance was used to assess the strength of the relationship between bone indicators and somatic and body compositions, number of fractures, sports type, and years of training experience. The values of adjusted determination coefficients R2 were given. 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: fractures in relation to femoral neck Z-score. The interaction between the type of sport and the muscle mass (muscle type) with the lumbar spine Z-score was also examined. The effect size was calculated as eta-squared (η^2) (small effect: <0.06; medium effect: 0.06–0.14; large effect: >0.14). In all analyses, levels of significance were: $p<0.05$.

3. Results

Biometric characteristics

Significant differences were shown in all kinanthropometric and bone variables. Men in the combat group had significantly higher fat mass, fat-free mass, and muscle mass compared to the endurance runners group (large effects: >0.8). Men in the endurance runners group had significantly lower all bone indicators compared to the combat group (large effects: >0.8), and significantly higher number of bone fractures in life (medium effect: 0.5–0.8) (Table 1).

Table 1. Biometric characteristics of athletes (n = 129).

Variable	Endurance sports (n = 60)	Combat sports (n = 69)	p	*Hegdes' g*
	Mean SD			
Basic variables				
Age (year)	23.9 ±1.5	23.4 ±1.8	0.791	0.069
Training **e**xperience (year)	7.7 ±1.8	7.4 ±1.8	0.379	0.167
Kinanthropometric variables				
Body Height (cm)	175.9 ±5.8	180.5 ±6.5	**0.000***	0.744
Body Weight (kg)	71.4 ±4.07	91.5 ±15.20	**0.001***	1.753
PBF (%)	17.0 ±1.63	22.9 ±5.20	**0.015***	1.488
FM (kg)	12.1 ±1.55	21.7 ±8.71	**0.001***	1.478
FFM (kg)	59.2 ±3.15	69.8 ±7.21	**0.001***	1.863
MM (kg)	26.67±1.42	34.9 ±3.62	**0.014***	2.932
Bone variables Femoral neck				
BMD (g/cm2)	0.800 ±0.049	1.059 ±0.110	**0.000***	2.972
BMC (g)	4.605 ±0.387	5.800 ±1.200	**0.000***	1.303
Z-score	−2.084 ±0.415	0.049 ±0.640	**0.000***	3.898
Trochanter				
BMD (g/cm2)	0.740 ±0.076	0.933 ±0.116	**0.000***	1.982
BMC (g)	11.773 ±1.934	14.604 ±3.577	**0.000***	0.964
Z-score	−1.032 ±0.545	0.329 ±0.831	**0.000***	1.963

		Lumbar spine		
Total sBMD (g/cm2)	1.077 ±0.139	1.466 ±0.181	**0.000***	2.388
Total BMC (g)	74.300 ±13.957	105.427 ±24.079	**0.000***	1.558
Total Z-Score	−0.892 ±0.815	1.218 ±0.972	**0.000***	2.449
Bone fractures (n/per life)	1.03 ±1.1	0.46 ±0,6	**0.001***	0.656

BMD bone mineral density; **BMC** bone mineral content; **FM** fat mass; **FFM** fat free 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<0.05

Differences in the status of bone mineral density and history of fractures during life among endurance and combat sports

Femoral neck and lumbar spine BMD below the expected range for age was observed only in endurance sports. A significantly higher percentage of athletes without fractures was recorded in the combat sports group. Significantly more fractures (2 or more) were recorded in the endurance group compared to combat sports (31.6 vs 5.8%; medium effect: 0.354). Indeed, intergroup differences were observed in the location of bone stress fractures (large effect >0.5). In endurance sports, fractures most commonly affect the medial tibial stress syndrome and the foot and ankle. In combat sports, the most common fractures affected the fibula and/or tibia, as well as the upper extremity and ribs (Table 2).

Table 2. Mineralization status of bone and history of fractures during life.

Variable	Endurance sport	Combat sport	X^2	Φ	p
	%				
		Femoral neck Z-score			
Below the expected range for age	38.3	0	59.66	0.680	**0.000***
The expected range for age	61.7	100			
		Lumbar Spine Z-score			
Below the expected range for age	13.3	0	9.808	0.276	**0.002***
The expected range for age	86.7	100			
		Number of men with bone stress fractures			
No fractures	41.7	59.4	16.19	0.354	**0.001***
With 1 fracture	26.7	34.8			
With 2 fractures	18.3	5.8			
With 3 or more fractures	13.3	0			
		Location of bone stress fractures			
Medial tibial stress syndrome	31.4	0			
Anterior cortex tibial stress fractures	0	0			
Medial tibial plateau stress fractures	17.1	0			

Femoral neck stress fractures	8.6	0	37.26	0.769	**0.000***
Femoral shaft stress fractures	0	0			
Fibula and/or tibia	14.3	32.1			
Patella	0	0			
Medial malleolus	0	0			
Pelvis	2.9	28.6			
Foot and ankle	25.7	10.7			
Upper extremity and rib	0	28.6			

$\boldsymbol{X^2}$ – chi-squared test; $\boldsymbol{\Phi}$ – phi factor; ***p*** – *p*-value, levels of significance were: *p<0.05

Relationships between bone indicators and somatic and body compositions, number of fractures, training experience, and sports competition

The results of covariance analyses showed that BMD (g/cm^2) was significantly influenced by muscle mass (kg), number of fractures (n/per life), and sport type (adj. R^2 = 0.732). In turn, BMC was affected by the body height (cm) and type of sports competition (adj. R^2 = 0.394). Z-score was influenced by the number of fractures (n/per life), and sport type (adj. R^2 = 0.725), (Table 3).

Table 3. Relationships between femoral neck bone indicators and somatic, body compositions, number of fractures, training experience, and sports competition (results of ANCOVA analyses).

Variable	BMD (g/cm^2)			BMC (g)			Z-score		
	F	η²	p	F	η²	p	F	η²	p
Body Height (cm)	0.736	0.006	0.393	5.992	0.047	**0.016***	1.354	0.011	0.247
Body Weight (kg)	1.238	0.010	0.268	2.849	0.023	0.094	2.681	0.022	0.104
FM (kg)	1.320	0.011	0.253	2.840	0.023	0.095	2.774	0.022	0.098
MM (kg)	11.095	0.284	**0.002***	2.524	0.020	0.115	2.623	0.021	0.108
Number of fractures (n/per life)	19.344	0.138	**0.000***	0.072	0.001	0.789	16.019	0.117	**0.000***
Training experience (years)	0.045	0.000	0.832	0.504	0.004	0.479	0.135	0.001	0.714
Sports competition (type)	5.685	0.169	**0.024***	5.775	0.171	**0.021***	10.115	0.216	**0.001***
F (p) adj. R²	50.9	0.73	**0.000***	12.88	0.39	**0.000***	49.22	0.72	**0.000***

BMD bone mineral density; **BMC** bone mineral content; **MM** muscle mass; **F** Ronald A. Fisher's test; adj. $\mathbf{R^2}$ the adjusted R-squared values of determination; **η²** eta-squared, effect size; **p** p-value, levels of significance were: *p<0.05

All analysed bone indicators (BMD, BMC, and Z-score) were significantly influenced by muscle mass and type of sport (adj. R^2 from 0.481 to 0.693), (Table 4).

Table 4. Relationships between lumbar spine bone indicators and somatic, body compositions, number of fractures, training experience, and sports competition (results of ANCOVA analyses).

Variable	BMD (g/cm²)			BMC (g)			Z-score		
	F	η^2	p	F	η^2	p	F	η^2	p
Body Height (cm)	0.006	0.000	0.937	1.109	0.009	0.294	0.004	0.002	0.948
Body Weight (kg)	0.309	0.003	0.579	0.042	0.000	0.838	0.432	0.004	0.512
FM (kg)	0.394	0.030	0.532	0.032	0.000	0.859	0.528	0.005	0.469
MM (kg)	20.422	0.144	**0.000***	5.755	0.162	**0.022***	5.612	0.136	**0.031***
Number of fractures (n/per life)	0.074	0.001	0.787	0.120	0.001	0.730	0.136	0.001	0.724
Training experience (years)	0.281	0.002	0.597	0.005	0.000	0.945	0.021	0.000	0.886
Sports competition (type)	14.101	0.104	**0.000***	19.501	0.139	**0.000***	16.561	0.120	**0.000***
F (p) adj. R^2	42.03	0.69	**0.000***	18.17	0.48	**0.000***	41.84	0.69	0.000*

BMD bone mineral density; **BMC** bone mineral content; **MM** muscle mass; **F** Ronald A. Fisher's test; adj. **R^2** the adjusted R-squared values of determination; **η^2** eta-squared, effect size; **p** P-value, levels of significance were: *p<0.05.

The effects of sport type, fractures and muscle mass on Z-score

The main effect of fracture was statistically significant, $F(1.125) = 44.48$, $p<0.001$, $\eta^2 = 0.262$. This indicates that the presence of a fracture indicates that individual differences make a significant contribution, affecting the femoral Z-score compared to cases without fractures. The effect size is large, suggesting a strong relationship between fracture status and bone score. The effect of sport type was also statistically significant, $F = 210.40$, $p < 0.001$, $\eta^2 = 0.627$, indicating that individual differences make a significant contribution. This result indicates substantial inter-individual variability in femoral Z-score values across patients. The effect size is very large, indicating that individual differences make a significant contribution to the observed variance. A significant fracture × sport type interaction was observed, $F(1.125) = 7.63$, $p = 0.0066$, $\eta^2 = 0.058$. This suggests that the effect of fracture on the femoral Z-score varies across sport types. The interaction has a moderate effect size, and the statistical power (0.786) indicates adequate sensitivity to detect this effect. Two-factor analysis of variance showed a significant effect of the sport type factor on the lumbar spine Z-score, while the muscle type factor and the interaction between the factors did not reach statistical significance (Table 5).

Table 5. Two-way ANOVA assessing the main effects and interaction of sports competition and number of fractures on femoral neck Z-score (model 1), as well as sports competition and muscle mass on lumbar spine Z-score (model 2).

Source of Variation	**Model 1 Femoral neck Z-score**				
	MS	***F***	***P-value***	***η2***	***Power***
Factor A Sports competition (type)	84.738	210.396	<0.001	0.627	1.0
Factor B Fractures (yes/no)	17.916	44.483	<0.001	0.262	1.0
A x B Interaction	3.075	7.634	0.007	0.058	0.8
Error	0.403	-	-	-	-
Source of Variation	**Model 2 Lumbar spine Z-score**				
	MS	***F***	***p-value***	***η2***	***Power***
Factor A Sports competition (type)	20.574	25.150	**<0.001**	0.167	1.0
Factor B Muscle mass (muscle type)	0.612	0.748	0.476	0.012	0.2
A x B Interaction	-	-	-	-	-
Error	0.818	-	-	-	-

MS mean square; **F** F-statistic; **p-value** significance level; **η²** eta squared, effect size

4. Discussion

Our findings revealed significantly higher BMD and bone mineral content (BMC) in both regions (the hip and the lumbar spine) of interest among combat sport athletes, such as Brazilian jiu-jitsu, judo, wrestling, compared to those engaged in endurance sports, who were predominantly long-distance, such as marathon, half-marathon, ultra running, and cross-country running. BMD values in the femoral neck and lumbar spine below the expected range for age were observed exclusively in endurance athletes. Moreover, a significantly higher proportion of athletes without a history of fractures was found in the combat sports group. Conversely, multiple fractures (two or more) were significantly more frequent in the endurance sports group. Intergroup differences were also observed in the anatomical distribution of BSF. In endurance sports, fractures most commonly involved the medial tibial region and the bones of the foot and ankle. In combat sports, the most frequent fracture sites included the fibula and/or tibia, as well as the upper extremities and ribs.

This study revealed significant main effects of both sport type and fracture status on the femoral Z-score, with large effect sizes, indicating that these factors substantially influence BMD. A significant interaction between sport type and fracture status suggests that the impact of fractures on femoral bone indicators differs depending on the type of sport practiced. In contrast, for the lumbar spine Z-score, only the effect of sport type reached statistical significance, indicating that this skeletal region is primarily influenced by sport-specific mechanical loading rather than fracture history.

Similar results in comparative research on combat sports with other sports disciplines showed that athletes participating in "weight-bearing" sports (judo, wrestling) had higher BMD than the endurance athletes and inactive individuals Sagayama et al. [19]. The mean whole-body BMD of judokas and wrestlers was higher than that of endurance athletes and non-athletes. Nasri et al. [20] found in their research that martial arts (hand-to-hand combat systems – see dictionary) training promotes higher BMD in boys/young men compared to their non-training peers. In the earlier cross-sectional surveys with Polish, Caucasian boys from three physical activity groups: speed-power athletes, such as throwing athletes and martial arts (hand-to-hand combat systems), water sports such as swimming water polo, diving, and inactive, also showed that 'weight-bearing, sportsmen (throwing athletes and hand to hand fight) had higher hip BMD and lumbar BMC [21].

A systematic review of bone studies using both HR-pQCT and DXA methods, conducted on athletes, showed that in high-impact sports, athletes have denser, stronger bones and better microarchitecture than low-impact athletes [22]. Comparative studies assessing BMD of the lumbar spine and proximal femur across various sports disciplines, including running, cycling, triathlon, team sports, combat sports and power sports, as well as ballet, have consistently shown the highest BMD values in athletes participating in combat sports and power sports [23]. Lower BMD in endurance sports compared to speed and power disciplines, combat sports, or team sports, both in young professional athletes and adults, as well as in the masters category, has been demonstrated in numerous studies of various ethnic groups [24-26].

Weight-bearing exercise is widely recognized as beneficial for maintaining long-term bone health. The mechanism of this effect is influenced by training indicators, especially the type of load [27-29]. Frequency, intensity, and variability of force directions are crucial for the osteogenic effect. On the other hand, low loads, long-term, monotonous loads (e.g., long-distance running, cycling) have a smaller osteogenic effect [30, 31].

The condition of athletes' bone tissue is determined by multiple factors, which is why this study analysed not only the degree of bone mineralization, but also the history of bone stress fractures and their relationship to BMD levels in the hip and spine. We revealed significant main effects of both sport type and fracture status on the femoral Z-score, with large effect sizes, indicating that these factors substantially influence BMD. Bone stress fractures are often defined as the result of cumulative microtrauma to the bone due to repetitive stress. High-intensity training, improper exercise technique, and low BMD can increase the risk of BSF [32].

In the present study, among endurance athletes, fractures most frequently affected the medial aspect of the tibia as well as the bones of the foot and ankle. In combat sports, the most common fracture sites involve the fibula and/or tibia, as well as the upper extremities and ribs. Stress fractures were also more frequent in the endurance sports group compared to the combat sports group. Two or more bone stress fractures occurred in over 30% of endurance athletes.

A study by Hutson et al. [33] found that between 3% and 21% of endurance runners experienced at least one bone stress injury, including stress fractures and bone stress reactions, within a single year. A study by Jones et al. [34] found that the rate of lower extremity stress fractures among distance runners was 8–13%. However, analyses of the incidence of BSF in combat sports are scarce, and most studies of athletes from various combat sports focus on fractures in general. A study by Hallaçeli et al. [35] found that fractures accounted for 29% of all injuries among muay thai athletes. Most of these fractures occurred in the lower extremities, particularly the shins, which may be a result of intense bone-on-bone contact during kicking.

Among MMM practitioners (in fact, neo gladiators – look in the dictionary), fractures accounted for 19% of all injuries, according to an analysis by Bickley et al. [36] based on data from American emergency rooms. Lower extremity fractures were the most common, which may be due to techniques such as kicks or takedowns.

The observed differences in BSF locations and frequencies between endurance and combat sports athletes can be attributed to distinct biomechanical demands, training regimens, and injury mechanisms inherent to each sport. In endurance sports, such as long-distance running, marathons, and ultra marathons, the repetitive, high-impact loading on the lower extremities predisposes athletes to BSF in the tibia, particularly the medial aspect, as well as the foot and ankle. The tibia bears significant weight during activities like running, making it susceptible to BSF, especially in the medial region. Additionally, the foot and ankle are frequently involved due to the repetitive nature of foot strikes and the biomechanical stresses associated with running [37, 3, 8]. In contrast, combat sports like muay thai involve dynamic movements, including striking, grappling, and weight-bearing exercises, leading to a different pattern of BSF. The fibula is commonly affected due to its role in stabilizing the lower leg during various combat maneuvers. Upper extremity SFs are prevalent in sports involving repetitive arm movements, such as striking or grappling, while rib fractures are associated with impacts from strikes or falls [38, 39].

The variability in injury sites between endurance and combat sports underscores the importance of sport-specific training and injury prevention strategies tailored to the unique demands of each discipline. Understanding these patterns can aid in developing targeted interventions to mitigate the risk of BSF among athletes.

However, the perspective of combat sports analysed in this study (involving permanent physical contact with an opponent, unlike boxing, karate, fencing, kendo, etc.) is popular on global scale, and therefore the results of this research are particularly valuable in terms of health and survival. In terms of a complementary approach – as exemplified by Byeong Seok Min et al. [40] – it will be possible in future secondary analyses to use these universal bone density indicators to compare them with those of people undertaking other, even extreme, psychophysical activities. This line of analysis is based on the methodology of complementary research [41-44], with an emphasis on health and self-defence aspects as an important element of survival [45-48].

Limitations of the study

Despite the use of a precise research protocol, calibrated specialized measurement equipment, and the performance of the tests by specialists with extensive experience, the study has several limitations. One of them is the relatively small number of athletes in both groups, which does not allow the conclusions from the study to be extrapolated to the entire population of athletes in this age group. Another limitation of the study was that the assessment of bone tissue relied solely on DXA testing, whereas evaluating bone turnover markers in the blood could provide valuable data to complement the diagnosis of the skeletal system. In this project, the mineral content of bones was examined in two sports disciplines. It would be worthwhile to extend this research to other sports disciplines and conduct it in different age groups. Such research would reveal a broader aspect of the research problem.

Conclusions

In this study, there was a large and strong relationship between history of bone stress fracture, sport type, and bone mineral status. A significant fracture and sport type interaction was observed. This suggests that the effect of fracture on the femoral Z-score varies across sport types. Recommendations based on systematic diagnosis of bone mineral status can effectively prevent stress fractures in sports.

Data Availability Statement: The data supporting this study's findings are available from the corresponding author upon reasonable request.

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