

## Calcaneal Bone Quality and Physique in Elite Hungarian Male Athletes

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### 1. Abstract

Regular physical activity has favourable influence on the bone status. The purpose of this study was to analyze the relationships between the bone quality index (BQI) in the calcaneus and anthropometric variables in male elite athletes. Participants were Hungarian elite male athletes: kayak-canoe (KC, n=43); triathlon (T, n=16); track & field (TF, n=46); water-polo (WP, n=19). Their physique was characterised by Heath-Carter somatotype. Calcaneal Quantitative Ultrasound (QUS) parameters were registered by Sonost3000 densitometer. Differences in bone quality between the groups and correlation patterns between QUS and physique were analysed ( $p < 0.05$ ). There were significant differences in QUS parameters. T and TF had significantly higher SOS (speed of sound, m/s) values than WP. KC had lower SOS values than T athletes (TF:  $1519.3 \pm 16.0$ ; T:  $1512.9 \pm 20.8$ ; KC:  $1505.6 \pm 12.4$ ; W:  $1495.1 \pm 10.8$ ). BUA (broadband ultrasound attenuation, dB/MHz) was the largestest in TF but this only differed significantly from WP (TF:  $106.5 \pm 14.8$ ; T:  $98.9 \pm 11.5$ ; KC:  $98.7 \pm 16.5$ ; WP:  $92.2 \pm 8.8$ ). BQI ( $\alpha\text{SOS} + \beta\text{BUA}$ ) was higher in TF ( $92.0 \pm 16.7$ ) than in KC ( $79.2 \pm 13.1$ ), WP ( $69.3 \pm 10.0$ ); it was higher in T ( $84.8 \pm 19.6$ ) than WP. Muscle percentage correlated positively, while absolute bone measurements correlated inversely with bone parameters. Higher

QUS values were associated with lower endomorphy and mesomorphy, while more linear physiques correlated with better bone parameters. Physique and type of exercise training appear to be associated with bone status. Both weight-bearing and non-weight bearing exercise improve calcaneus bone parameters such as BQI to different extents. It might be preferable to combine some weight-bearing exercise during the sessions, and it is also highly recommended after a competitive period and during recreational sport activities.

**2. Keywords:** Weight-bearing and Non-weight-bearing Exercise; Ultrasound Bone Characteristics; Anthropometry; Somatotype

### 3. Introduction

Osteopenia and osteoporosis in males are becoming an increasingly important public health problem, and their prevalence in male patients is also high. Twenty percent of men over the age of 50 year will suffer an osteoporotic fracture during their lifetime [1,2]. Osteoporosis is about four times more common in women, but one in three patients with osteopenia (more frequent than osteoporosis) is a man [3].

Osteopenia associated with lower bone mass (new

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term of osteopenia is low bone mass) and lower bone density than in normal bone status. The treatment of osteopenia is complex, with an emphasis on developing a healthy lifestyle and most often medications are also recommended. Osteopenia is usually associated with no symptoms or pain, so it is often not diagnosed until after a fracture, that is why prevention is so important. Bone degeneration can be prevented, decreased or slowed down with regular physical activity. Cross-sectional studies have demonstrated greater bone mineral content and density in athletes [4,5,6,7,8]. Moreover, longitudinal studies confirm the beneficial effects of regular exercise on bone health [9, 10]. In adults bone remodeling highly depends on the effective mechanical loading of stimuli. Weight-bearing activity has a beneficial effect on the skeleton through gravitational and muscular forces. Bones adapt to greater mechanical loading with adequate reconstruction in trabecular net and with higher density and thickness of the bone substance. Non-weight bearing activities have non-significant or little effect on bone density. Swimming and cycling are considered to be the types of physical activity that have low impact on bone density [11,12] however, they have a positive influence on other bone properties like elasticity and microstructure conforming by QUS [8]. Others reported divergent results in a study of male recreational athletes [13]. Cyclists, aged 20 to 59, were seven times more likely to have osteopenia in the spine than runners, controlled for age, body weight, and bone-loading history. According to a review it seems that cyclist's BMD correlates positively with the cumulative amount of bone loading forces experienced over their lifetime [14]. There is a negative correlation between bone mineral density and dermal calcium losses during exercise, also [14]. Bone density parameters increase in parallel with the level of mechanical loading and with the level of intensity of sport activities. It was found that athletes from different

combat sports had higher BMD values than water polo athletes [15]. Running and ball games improve bone density [16]; and ultrasound bone parameters were higher in footballers than in swimmers, the latter group exceeded the values of the sedentary control group [17]. In several studies a positive osteogenic effect of different sports on bone density improvement has been detected with Dual-energy X-ray Absorption (DXA) [4,7,15,18]. However, these DXA measurements give no suitable information as to other qualities of bone structure, such as elasticity, microarchitecture and fracture risk. Quantitative ultrasound measurement (QUS) provides information not only about bone mineral mass or density but also its quality parameters.

Some previous studies have analyzed somatotype differences in athletes. In a study was found that athletes in throwing events differed from other athletes [19] others found relationships between extreme ectomorphic constitution and performance in track and field athletes [20] and young Portuguese triathletes were considered mainly ectomorphic mesomorphs [21]. Carter and Heath analysed the somatotype differences between various Olympic and other sports participants [22]. In a study was found that elite water polo players belonged to the balanced mesomorph somatotype category [23].

Not many investigations have focused on the differences in bone properties measured with QUS in athletic males. Furthermore, no results of the relationship between physique and quantitative ultrasound bone parameters have been published.

The main aim of this study was to verify the relationships between different weight-bearing and non-weight-bearing activities, anthropometric parameters and bone quality in elite male athletes in the calcaneus bone. Our questions were: 1. Can sports with different mechanical loading result in difference in the ultrasound indicators of the calcaneus bone be found in male elite athletes? 2. Are there significant relationships between anthropometric and somatotype

components and calcaneus bone characteristics in male elite athletes?

#### 4. Material and Methods

Participants were elite Hungarian male athletes (N=124; kayak-canoe: 43; triathlon: 16; track and field: 46; water polo: 19). All competed at an international level, achieved at least sixth position in the national championships and participated in international competitions (kayak-canoe:  $22.66 \pm 4.23$ ; triathlon:  $23.47 \pm 6.22$ ; water polo:  $25.33 \pm 4.26$ ; track and field  $21.7 \pm 4.17$ ). To select the male elite athletes, they filled in a standard valid questionnaire and took part in a personal interview during which we also asked about their current and past organized and other habitual physical activities, as well as the best results in elite athletes. The athletes' sport related experience and number of training hours per week were: kayak-canoe:  $13.63 \pm 6.35$  years and  $21.5 \pm 4.3$  hours per week; triathlon:  $10.47 \pm 4.23$  years and  $20.00 \pm 5.20$  hours per week; water polo:  $16.65 \pm 4.78$  years and  $18.94 \pm 5.18$  hours per week; track and field  $12.52 \pm 5.78$  years and  $18.5 \pm 3.60$  hours per week. All of the elite athletes served as volunteers in line with the principles of the Declaration of Helsinki. All participants received written information about the goal of the survey and the procedures used. Data management was conducted anonymously. The protocol was approved by the Semmelweis University's institutional review board and the Medical Research Council of Hungary by the Scientific and Research Ethics Committee (14120-3/2014/EKU (133/2014)). The experiments carried out in this study comply with the current laws of Hungary. Anthropometric measurements were taken according to the International Biological Program [24]. The instruments were calibrated prior to use and all measurements were taken on the subject's right side. Anthropometric variables included body mass, body height, seven skinfolds (biceps, triceps, subscapular, suprailiac, abdominal, thigh and medial calf), two widths (elbow and knee), and six girths (upper arm

relaxed, upper arm flexed and tensed, lower arm, thigh, maximum calf and ankle). Body height was measured with a stadiometer (Sieber-Hegner, Switzerland) to the nearest 0.1 cm, and the body weight was recorded on a portable scale (model 707, Seca Corporation, Columbia, Maryland) to the nearest 0.1 kg. Nutritional status was calculated by BMI ( $\text{kg}/\text{m}^2$ ). Skinfolds were measured using a caliper (Lange Ltd, Cambridge, Maryland) to the nearest 0.5 mm, widths were taken with Sieber-Hegner (Switzerland) anthropometric set; girths were measured with a flexible metallic tape measure (Holtain Ltd) to the nearest 0.1 cm. All measurements were repeated three times by skilled anthropometrists, and the average was employed in further calculations. The accuracy of repeated measurements were 1 mm and 0.5 mm in skinfolds.

Body fat percentage estimation followed the modified procedure of Parízková [25,26]

$\text{Fat}\% = 28.894 \times \log$

$[2(\text{biceps} + \text{triceps} + \text{subscapular} + \text{suprailiac} + \text{calf skinfolds})] - 41.18.$

Body composition was assessed with the Drinkwater and Ross technique [27]. Bone and muscle mass were determined based on the following equations:

Bone mass (kg) =  $[1.57 \times 0.25 \times (zb_1 + zb_2 + zb_3 + zb_4) + 10.49]/(\text{hc}^3)$

Muscle mass (kg) =  $[2.99 \times 0.2 \times (zm_1 + zm_2 + zm_3 + zm_4 + zm_5) + 25.55]/(\text{hc}^3)$

$zb_1 = (\text{elbow width} \times \text{hc} - 6.48)/0.35$ ;  $zb_2 = (\text{knee width} \times \text{hc} - 9.52)/0.48$ ;

$zb_3 = (\text{wrist girth} \times \text{hc} - 16.35)/3.14/0.72$ ;  $zb_4 = (\text{ankle girth} \times \text{hc} - 21.71)/3.14/1.33$ ;

$zm_1 = [(\text{upper arm relaxed} - 0.314 \times \text{triceps skinfold}) \times \text{hc} - 22.05]/3.67$ ;

$zm_2 = [(\text{chest girth} - 0.314 \times \text{subscapula skinfold}) \times \text{hc} - 82.36]/4.68$ ;

$zm_3 = (\text{lower arm girth} \times \text{hc} - 25.13)/1.41$ ;

$zm_4 = [(\text{thigh girth} - 0.314 \times \text{thigh skinfold}) \times \text{hc} - 44.34]/3.59$ ;

$zm_5 = [(calf\ girth - 0.314 \times calf\ skinfold) \times hc - 30.22]/1.97$ ;  $hc = 170.18/height$ .

Physique was characterised by the Carter and Heath somatotype method, based on the following equations [22].

Endomorphy\* (relative fatness) =  $-0.7182 + 0.1451(X) - 0.00068(X^2) + 0.0000014(X^3)$

X = sum of triceps, subscapular, and suprailiac skinfolds; \*(for height-corrected endomorphy, X is multiplied by  $170.18/height$  in cm);

Mesomorphy (relative robustness) =  $(0.858 \text{ humerus width} + 0.601 \text{ femur width} + 0.188 \text{ corrected arm girth} + 0.161 \text{ corrected calf girth}) - (height \times 0.131) + 4.50$ ;

Ectomorphy (relative linearity) =  $0.732 \times (height \times weight^{-0.33}) - 28.58$ ;

Calcaneal quantitative ultrasound (QUS) parameters were registered with a Sonost 3000 bone densitometer. Two trained authors performed all measurements by positioning participants' right **foot** properly. Quantitative ultrasound measurement (QUS) is relatively inexpensive, portable, non-invasive and radiation-free method of evaluating bone status. It provides information not only about bone mineral mass or density but also its quality parameters. Variables, measured by QUS, are as follows: Speed of sound (SOS), which reflects elasticity and microarchitecture rather than bone mineral mass, was shown to predict fractures independent of BMD, suggesting that it measures some aspects of bone strength. The value of SOS is changed by the propagation of wave and bone elasticity, the latter has a stronger influence on speed of sound than density, and therefore, shows the material quality of the bone. Broadband ultrasound attenuation (BUA) reveals the mineral content of bone showing the best correlation to BMD [28] and BMC; and it can be also a microstructural indicator of bone [29] BUA value depends on bone mass and the remaining intactness of trabecula-net. Bone Quality

Index ( $BQI = \alpha SOS + \beta BUA$ ,  $\alpha, \beta$ : temperature corrections) is derived from SOS and BUA with temperature correction and lower value of standard deviation, and fracture risk can be predicted with BQI, which makes it suitable for clinical use [30]. Base on its short time requirement, repeatability, the accuracy of repeated measurements were 0.5-1 unit in QUS parameters [29,31], portability and absence of ionizing radiation, QUS is suggested for screening work with athletes and population-based samples under the right clinical setting [32].

Data were analyzed with the use of Statistica for Windows software (version 11., StatSoft Inc., Tulsa, OK 74104, USA, 2011). All values were expressed as mean  $\pm$  standard deviation (SD). Differences in the respective subgroup's means were tested with MANOVA. In the case of significant F-values Bonferroni's post-hoc tests were used. Differences between subgroups by endomorphy and mesomorphy values were tested with Student's t-tests for independent samples.

We analysed the relationships between anthropometric variables and bone characteristics in the total sample and subgroups using a Pearson linear correlation. The level of effective random error was set at 5% in all significance tests ( $p < 0.05$ ).

## 5. Results

The basic statistics of anthropometric parameters of the subjects are shown in Table 1.

Water polo players were significantly taller and heavier than the others. Water polo players had the highest values in girth and width. The Body Mass Index (BMI) values of triathletes and track and field athletes were the lowest and differed from the results of other athletes. Bone percentage did not differ between the elite male athlete groups. Nevertheless, the bone measurements (for example, elbow and knee width, and ankle girth) were significantly higher for the water polo and kayak-canoe subgroups.

Somatotype components differed significantly in the elite male athlete groups. Ectomorphy was the highest

**Table 1:** Descriptive statistics of absolute and derived anthropometric parameters in the four male elite athlete groups (Mean±SD; df=3).

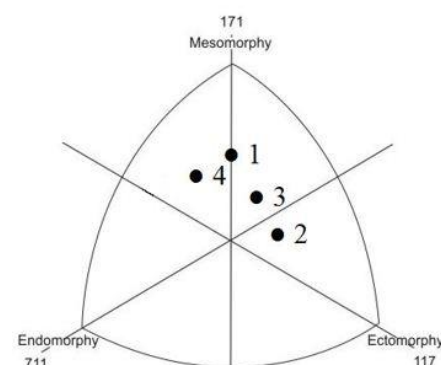
Kayak-Canoe (1)		Triathlon (2)	Track and Field (3)	Water Polo (4)	F value
Body height (cm)	183.0±6.31	179.5±6.5	180.6±7.2	195.9±4.4 <sup>123</sup>	27.38
Body weight (kg)	82.80±8.16 <sup>23</sup>	70.7±5.7	71.1±10.9	98.5±9.7 <sup>123</sup>	44.07
Biceps skinfold (mm)	4.0±0.8	4.4±1.5	4.8±2.2	4.9±2.1	1.78
Triceps skinfold (mm)	6.7±2.3	7.3±3.2	7.3±3.0	9.0±3.1	2.92
Subscapular skinfold(mm)	9.1±2.2	8.5±1.5	9.7±3.0	13.9±3.9 <sup>123</sup>	14.52
Suprailiac skinfold (mm)	9.8±3.4	9.1±3.2	8.5±4.5	14.6±6.3 <sup>123</sup>	8.79
Abdominal skinfold (mm)	11.3±4.6	10.5±4.5	12.3±5.0	19.6±8.4 <sup>123</sup>	11.65
Thigh skinfold (mm)	12.4±4.7	9.8±2.8	10.4±2.9	14.2±4.6	0.49
Calf skinfold (mm)	7.7±3.3	6.4±2.4	6.8±2.3	10.8±3.6 <sup>23</sup>	7.56
Elbow width (cm)	7.4±0.3 <sup>23</sup>	6.9±0.4	7.1±0.3	7.9±0.3 <sup>123</sup>	33.49
Knee width (cm)	10.0±0.4	9.7±0.5	9.8±0.5	10.8±0.4 <sup>123</sup>	22.11
Upper arm girth (cm)	32.2±2.5 <sup>23</sup>	27.4±1.5	27.7±2.8	35.9±2.3 <sup>123</sup>	58.27
Upper arm flexed girth (cm)	35.9±2.4 <sup>23</sup>	30.3±1.9	30.8±3.0	38.8±2.4 <sup>123</sup>	60.48
Lower arm girth (cm)	29.4±1.6 <sup>23</sup>	26.2±1.3	26.1±1.8	30.9±1.1 <sup>123</sup>	59.78
Wrist girth (cm)	17.1±0.9	16.4±0.7	16.4±1.6	18.3±0.8 <sup>123</sup>	11.83
Thigh girth (cm)	56.1±3.6	52.3±2.9	55.1±4.3	59.8±3.0 <sup>123</sup>	11.99
Calf girth (cm)	37.2±1.8	35.8±1.6	36.9±2.3	38.8±3.1 <sup>123</sup>	5.4
Ankle girth (cm)	23.2±1.1 <sup>23</sup>	21.9±1.2	22.1±1.1	23.8±1.2 <sup>23</sup>	12.88
Chest girth (cm)	102.2±4.4 <sup>23</sup>	92.1±3.7	90.5±6.1	111.0±4.3 <sup>123</sup>	87.19
BMI (kg/m <sup>2</sup> )	24.7±1.7 <sup>23</sup>	21.9±1.4	21.8±2.6	25.8±2.1 <sup>23</sup>	22.85
Fat%	14.4±4.1	15.1±3.7	12.4±3.4	17.0±3.4 <sup>3</sup>	7.45
Bone%	16.5±1.0	16.8±1.3	16.9±1.5	16.2±0.9	1.62
Muscle%	47.7±1.6 <sup>34</sup>	46.2±1.8	46.1±2.5	45.8±1.9	5.5
Bone%/Muscle%	0.3±0.0	0.4±0.0	0.4±0.0	0.3±0.0	2.91
Endomorphy I	2.4± 0.8	2.4± 0.8	2.4± 0.9	3.4± 0.9	7.04
Mesomorphy II	4.7±1.0 <sup>23</sup>	3.4±0.7	3.7±1.2	4.7±0.9 <sup>23</sup>	10.07
Ectomorphy III	2.2±0.8	3.2±0.8	3.4±1.2 <sup>14</sup>	2.5±0.8	12.69

BMI: Body Mass Index; significant differences are shown by upper index of subgroups (p<0.05), index numbers show significance differences between respective subgroups.

in triathletes and track and field athletes. When the male elite athlete groups were grouped according to their somatotype, triathletes and track and field athletes belonged to the central category; water polo players to the endomorphic-mesomorph category and kayakers-canoeists to the balanced mesomorph category.

Triathletes and track and field athletes had significantly higher SOS values than water polo players (p=0.005; p=0.000). Kayakers-canoeists had lower SOS values than track and field athletes

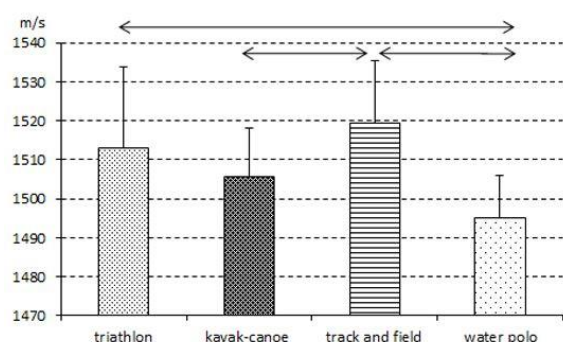
(p=0.000) (triathlon: 1513.91±20.80; kayak-canoe:



**Figure 1.** Somatotypes of the subgroups. 1=Kayak-Canoe, 2=Triathlon, 3=Track and Field, 4=Water Polo.

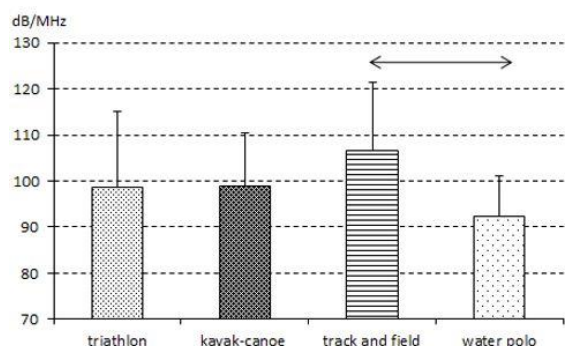


1505.61±12.41; track and field: 1519.30±16.00; water polo: 1495.15±10.85) (df=3; F=13.582).



**Figure 2.** Speed of Sound (SOS) of calcaneus in subgroups (Mean±SD). SOS reflects elasticity, microarchitecture and strength of bone. Abbr.: ↔ significant differences.

The BUA mean was lowest in the water polo players; every other sporting group had higher results (Figure 3). Track and field athletes had the largest BUA mean, but this statistic only differed significantly from water polo players ( $p=0.009$ ) (triathlon: 99.13±11.49; kayak-canoe: 98.73±16.48; track and field: 106.51±14.82; water polo: 92.20±8.83) (df=3; F=5.827).



**Figure 3.** Broadband Ultrasound Attenuation (BUA) of calcaneus in subgroups (Mean±SD). BUA depends on bone mass and trabecula-net status. Abbr.: ↔ significant differences.

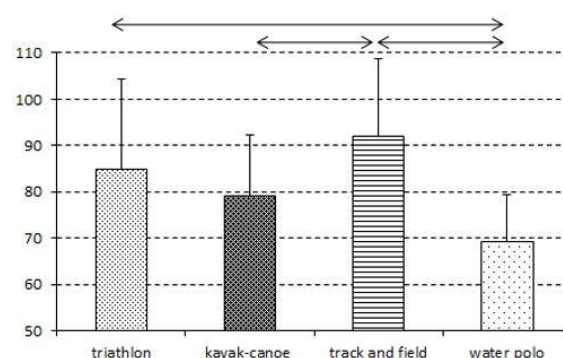
In terms of Bone Quality Index (Figure 4), the highest mean value was found in track and field athletes, with the lowest values in water polo players ( $p=0.000$ ),

**Table 2:** Correlation pattern of anthropometric and QUS parameters in total sample of male elite athletes  
Significant correlation coefficients in *italics* ( $p<0.05$ ).

Total Sample (r)	SOS (m/s)	p	BUA (dB/MHz)	p	BQI	p
Body Height (cm)	-0.3	0.001	-0.17	0.071	-0.25	.008
Body Weight (cm)	-0.33	0.001	-0.15	0.112	-0.28	0.003
BMI (kg/m <sup>2</sup> )	-0.24	0.008	-0.1	0.213	-0.21	0.028
Fat%	-0.19	0.045	-0.12	0.201	-0.19	0.049

with differences among the subgroups (kayak-canoe: 79.23±13.08; triathlon: 84.76±19.63; track and field: 91.97±16.67; water polo: 69.31±10.05) (df=3; F=11.423).

Table 2. summarizes the correlation pattern of ultrasound bone parameters and anthropometric variables in the total sample of male elite athletes.



**Figure 4.** Bone Quality Index (BQI) of calcaneus in subgroups (Mean±SD). BQI is derived from SOS and BUA with temperature correction and predicts fracture risk. Abbr.: ↔ significant differences.

Bone characteristics had a small to medium negative correlation with body height, body weight, BMI, and relative fat percentage in the total sample. Relative muscle mass correlated positively with bone parameters. Nevertheless, bone percentage and QUS parameters did not correlate with each other, and there was a slight to medium inverse but significant correlation between absolute bone sizes and ultrasound SOS and BQI values.

A small correlation was found between QUS and somatotype components, especially with endomorphy. The higher values of QUS were associated with lower endomorphy and mesomorphy values and a more linear physique was associated with better bone parameters.

Muscle%	0.17	0.049	0.16	0.053	0.19	0.045
Bone%	0.16	0.066	0.05	0.593	0.15	0.098
Bone%/Muscle%	-0.13	0.067	-0.13	0.068	-0.14	0.062
Elbow width (cm)	-0.31	0.001	-0.15	0.116	-0.26	0.005
Knee width (cm)	-0.24	0.003	-0.08	0.371	-0.21	0.03
Ankle girth (cm)	-0.2	0.024	-0.04	0.644	-0.2	0.031
Endomorphy	-0.18	0.048	-0.16	0.053	-0.19	0.047
Mesomorphy	-0.18	0.049	-0.1	0.117	-0.12	0.097
Ectomorphy	0.16	0.067	0.07	0.857	0.17	0.049

No significant correlation was found in the subgroups between anthropometric and bone parameters, except in the kayak-canoe subgroup (SOS with mesomorphy,  $r=0.37$ ,  $p=0.028$ ; BUA with Bone%,  $r=0.39$ ,  $p=0.020$ ; Bone%/Muscle%,  $r=0.36$ ,  $p=0.031$ ; Elbow, knee width with QUS,  $r=0.36-0.44$ ,  $p=0.031-0.007$ ).

## 6. Discussion

The objective of this study was to compare elite male athletes from various sports in terms of different effective mechanical loading stimuli on the calcaneus bone. We investigated track and field athletes (with high impact, and weight-bearing exercises), triathletes (running is a high impact, weight-bearing exercise combined with also non-weight bearing activities like cycling and swimming), kayakers and canoeists (non-weight bearing exercises with a low impact, weight bearing training and light running), water polo players (non-weight bearing exercise). There were significant differences in ultrasound calcaneus bone parameters between triathlon and track and field athletes, despite the high level of weight-bearing activity present in both sports. However, each training regime of different track and field athletes involves weight-bearing activities. In the case of triathletes, the ratio of declining weight-bearing activities of the three sports (running – cycling – swimming) is almost the same, and this is well reflected in their ultrasound calcaneus bone parameters.

Several studies have analysed the sports-specific relationship of bone density with DXA [32]. However, DXA only measures the bone status in terms of bone mineral density. In the last decade there

has been a growing need for the use of non-invasive quantitative ultrasound methods to demonstrate both bone density and microarchitectural changes. In addition, only a few studies have investigated the bone status of kayakers-canoeists [33] water polo players [15,34] and triathletes [35].

Because of the limited data regarding kayakers, we had to rely on the results of ten elite kayakers (six males, four females) [33]. A greater BMD was found in flatwater sprint kayakers than in controls in most upper body sites; total body and lower body sites' BMD did not differ except for the pelvis. Strong correlations were found between BMD in upper body sites and lean body mass and body weight and fat percentage in controls. In contrast, we found a significant correlation between anthropometric and ultrasound bone parameters (SOS with mesomorphy; BUA with Bone%, Bone%/Muscle%; QUS with elbow, knee width) in the kayak-canoe subgroup.

Others investigated combat sport athletes and water polo players with DXA [15]. It was found that water polo players had significantly lower BMD, higher fat mass and did not differ from control individuals in these parameters, however, appendicular muscle mass was obviously higher in the athletes than in the controls. A similar trend was observed with the use of QUS in our comparison to other sports; even the mean of SOS and BQI in water polo players showed the lowest value, and the world leading water polo players could be characterized by a lower specific gravity.

In a Chinese study [17] male students ( $N=55$ ) were categorized according to their main sport activities (soccer, dancing, swimming and sedentary group). A

significant linear increase was found in all QUS parameters with increasing weight-bearing and high impact exercise. Others reported that aquatic athletes and controls had lower bone values than jumpers, measured with SPA (single energy photon absorption) as well as with QUS bone densitometry [35].

Our study confirms that the values of bone characteristics differ in parallel with the level of mechanical loading in different sport activities (from highest to lowest bone values): track and field athletes; kayakers-canoeists; triathletes; water polo players. Our answer to our first question is that the different sports really result in difference in the ultrasound indicators of the calcaneus bone.

Anthropometric variables and bone status were investigated in some previous studies, but those focused on the effect of body fat on bone density. They stated that overweight and obese conditions are sometimes associated with lower bone density [36]. Divergent results have also been reported that is obesity (gravitational force) may protect against osteoporosis [37,38,39,40]. However, recent studies have shown conflicting results; nowadays there is growing evidence that obesity, particularly severe obesity, may be related to an increased risk of fracture at different skeletal sites, which is partially independent from BMD. In our sample higher body fat percentage values were associated with lower QUS bone parameters.

Thus, we investigated the relationships between muscle and bone mass, bone sizes, as well as somatotype components and bone characteristics. As we found no correlation between relative bone percentage and ultrasound bone parameters, we suspect that it has no major effect on bone health. On the contrary larger bone sizes were associated with lower values of QUS parameters.

Because of the limited available data about the link between somatotype and bone density in athletes, our findings should be treated with care and require further investigation and analysis. Only one previous

study has evaluated the association between skeletal aging traits (obtained from an evaluation of bone of hand radiographs) and characteristics of physique [41]. They reported a moderate but significant connection between skeletal aging traits and somatotype from 18 to 90-year-old Chuvasha individuals (n=1190, Russian Federation).

Only one investigation has focused on osteoporosis risk factors in association with somatotype in 70 healthy males aged 45 to 65 years using DXA [42]. They found a moderate positive correlation between lumbar and total femur BMD and endomorphy and mesomorphy; and a negative correlation with ectomorphy. They assumed that somatotype, primarily endomorphy, together with daily energy expenditure may be important for estimating osteoporosis risk factors in males. We also found significant relationships between somatotype components and ultrasound bone parameters. Nevertheless, in the total sample of male elite athletes our results (Table 2) contradicted their findings: endomorphy and mesomorphy negatively correlated with QUS results, and a small positive correlation was found between ectomorphy and bone parameters. Thus, based on our studies, we can state that all three somatotype components showed a relationship with calcaneus bone characteristics in this sample.

According to the literature, marked endomorphy is associated with lower QUS values, which is consistent with the unfavourable bone characteristics of overweight and obese individuals [36,39]. The dominant relative linearity – ectomorphy – is connected to higher SOS, BUA and BQI values, and although track and field athletes and triathletes had higher ectomorphy values, they performed a higher intensity weight-bearing exercise [43,44].

There was a striking inverse correlation between mesomorphy and bone parameters for the whole sample, and a positive correlation could be detected in the kayak-canoe subgroups. However, dominant



mesomorphy without notable endomorphy correlated with better bone characteristics in athletes.

Correlations of somatotype and bone health should also be investigated in females. In addition, body proportions, primarily length and width dimensions of lower extremities, may also be associated with bone health.

## 7. Study limitations

The results of this study are limited due to its cross-sectional nature and their small sample size. The track and field athletes were specialized in different kind of sports (jumpers, sprinters, marathonists, etc), and we could not separate them into small subgroups. Although ultrasound bone measurements correlate highly with BMD of the total body measured with DXA, only a single body region's bone parameter such as the calcaneus can be detected with QUS. However, SOS reflects elasticity and microarchitecture rather than bone mineral mass. It can also predict fracture risk independently of BMD, suggesting that SOS measures other aspects of bone status. BUA has the highest correlation with BMD, and it can be also a microstructural indicator of bone complexity. BQI is derived from the two latter with temperature correction and with a lower value of standard deviation. Therefore, BQI is a suitable parameter for clinical use and non-invasive QUS is highly recommended to investigate bone properties in athletes. All of the variables of physique – including somatotype – both quantitative and qualitative indicators of bone slowly and gradually change with aging. These two examined properties (physique and bone parameters) are obviously influenced by lifestyle. The complexity of the issue and the very limited available data need further investigation.

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## 8. Conclusions

Our results suggest that the male elite athlete's type of sport activity with high mechanical loading on the skeleton may be an important factor in achieving a high peak bone mass and reducing the risk of osteopenia or osteoporosis later in life.

The training methods of non-weight bearing sports suggest that it might be preferable to include some weight-bearing exercise during the sessions, and it is also highly recommended after a competitive period and during recreational sport activities, as well.

Somatotype is a holistic approach of human body structure; so, its connection with local bone parameters requires further investigation either in athletes or in non-athletes.

Our results do provide relevance as to weight- and non-weight bearing exercise's impact on bone quality. According to the authors, QUS is a sensitive enough method to reflect the difference in the effect of sport-specific loads (weight-bearing and non-weight-bearing) on calcaneus bone. Both weight-bearing and non-weight bearing exercise improve calcaneus bone parameters such as BQI to different extents. It might be preferable to combine some weight-bearing exercise during the sessions, and it is also highly recommended after a competitive period and during recreational sport activities.

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