Original paper

A comparison of bone mineral density and bone mineral content and soft-tissue composition between male volleyball players and inactive men

Porównanie gęstości i zawartości mineralnej kości oraz składu tkanek miękkich pomiędzy siatkarzami i nieaktywnymi fizycznie mężczyznami

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Key words: bone mineral density, muscle strength, dual-energy X-ray absorptiometry, volleyball players, body composition.

Słowa kluczowe: gęstość mineralna kości, siła mięśniowa, dwuwiązkowa absorpcjometria rentgenowska, siatkarze, skład masy ciała.

Abstract

Introduction: Physical activity is an important environmental factor affecting skeletal remodeling and metabolism. Bone tissue reacts more effectively to dynamic loading than static loading, and the maximum effect is achieved with weight-bearing activity. Therefore, volleyball players are appropriate groups for research on the impact of dynamic loading on different skeletal regions in examined athletes.
Aim of the research: To compare bone mineral density (BMD) and bone mineral content (BMC) and also soft-tissue composition, i.e. mass body fat (MBF) and lean body mass (LBM) between male volleyball players and physically inactive men. The relationships between selected parameters from the DXA (dual-energy X-ray absorptiometry) test and the strength of shoulder muscles were also assessed.
Material and methods: A group of 40 men aged 20–25 years was included in the study (20 male volleyball players, 20 inactive men). Body composition tests were performed with the DXA method with a Lunar iDXA. An IDO isometer was used to assess the isometric strength of muscle groups acting on the shoulder joint.
Results: Higher BMD and BMC parameters in almost all evaluated body parts were recorded in the group of volleyball players. There were no statistically significant differences between the MBF of volleyball players and the control group except for the trunk ($p = 0.045$). In the group of volleyball players, a significantly higher percentage of LBM content was observed. The presence of a statistically significant positive linear relationship between the shoulder muscle strength and BMD, BMC, and LBM of the upper limbs was confirmed.
Conclusions: Our study highlights the importance of impact forces acting on the skeleton and the systematic development of muscle strength to increase BMD and BMC.

Streszczenie

Wprowadzenie: Aktywność fizyczna jest istotnym czynnikiem środowiskowym wpływającym na przebudowę i metabolizm szkieletu. Tkanka kostna reaguje efektywniej na obciążenie dynamiczne niż statyczne, a maksymalny efekt osiąga się przy ćwiczeniach oporowych w obciążeniu masą własnego ciała. Siatkarze są odpowiednią grupą do badań spośród sportowców nad wpływem obciążenia dynamicznego na różne części szkieletu.
Cel pracy: Porównanie całkowitej i regionalnej gęstości (BMD) i zawartości (BMC) mineralnej kości oraz składu tkanek miękkich – masy tkanki tłuszczowej (MBF) i beztłuszczowej (LBM) pomiędzy siatkarzami a mężczyznami nieaktywnymi fizycznie. Ocenie poddano także zależności pomiędzy wybranymi parametrami z badania metodą dwuwiązkowej absorpcjometrii rentgenowskiej (DXA) dla kończyn górnych a siłą mięśni działających na stawy ramienne.
Materiał i metody: Badaniami objęto grupę 40 mężczyzn (20 siatkarzy i 20 nieaktywnych fizycznie mężczyzn) w wieku od 20 do 25 lat. Badania składu ciała wykonywano metodą DXA aparatem Lunar iDXA. Do oceny siły grup mięśniowych działających na staw ramienny w warunkach statyki posłużył ręczny dynamometr IDO Isometer.

Wyniki: Wyższą wartość parametrów BMD i BMC w większości poddanych ocenie części ciała wykazano w grupie siatkarzy. Nie stwierdzono obecności statystycznie istotnych różnic pomiędzy MBF u osób z grupy siatkarzy i kontrolnej dla większości parametrów, z wyjątkiem tułowia (p = 0,045). W grupie siatkarzy zaobserwowano istotnie większą wartość procentową LBM dla parametrów kończyn dolnych, tułowia oraz ogółem. Potwierdzono obecność statystycznie istotnej dodatniej, liniowej zależności w kończynach górnych pomiędzy momentem sił wybranych grup mięśniowych a BMD, BMC i LBM.
Wnioski: Nasze badania podkreślają znaczenie sił uderzenia działających na szkielet oraz systematycznego rozwoju siły mięśni w celu zwiększenia wartości parametrów BMD i BMC.

Introduction

Physical activity (PA) is a very important factor influencing public health. The World Health Organization (WHO) Regional Office for Europe (2015) has established recommendations for physical activity in adults between 18 and 65 years of age. In order to achieve measurable health benefits, moderate physical activity is recommended for at least 30 min 5 days a week, or very intense physical activity for at least 20 min 3 days a week [1]. Many clinical studies have shown that PA undertaken from an early age provides positive benefits for the development of a young person, and it influences taking up systematic physical activity later in life, bringing a lot of health benefits [2–4]. PA is an important environmental factor affecting skeletal remodeling and metabolism. Thanks to this, the correct muscle mass and bone mass are maintained. Regular exercise exerts a beneficial effect on bone mineralization [5]. PA is involved in the process of bone hypertrophy, i.e. the change in length, width, and shape. The right structure protects the bone against fractures. Laboratory studies have shown that weight-bearing loading is more effective in increasing bone mass than non-weight-bearing physical activities such as swimming, cycling, or horse riding. Bone tissue reacts more effectively to dynamic loading than to static loading, and the maximum effect is achieved with weight-bearing activity, including explosive exercises, such as jumping, turning, or sprinting [6–8]. Volleyball is a sport in which unusually high impact forces are generated during jumps and landings, and especially during plyometric exercises. In addition, it is also complemented by strength training to increase jumping power. Therefore, volleyball players are a good group for research on the impact of weight-bearing training on different skeletal regions [9, 10].

Regular PA in adults improves the flexibility and elasticity of joint capsules and ligaments [11]. It also affects the lipid profile by reducing the concentration of triglycerides, and it prevents overweight and obesity. Endurance training increases the intensity of fat metabolism and has a positive effect on the blood supply to skeletal muscles [12].

Aim of the research

The aim of the current study was to compare total and regional bone mineral density (BMD) and bone mineral content (BMC) and soft-tissue composition (mass body fat (MBF) and lean body mass (LBM)) between male volleyball players and physically inactive men aged 20–25 years. The assessment of the relationship between selected parameters from the DXA test and the strength of muscles acting on the shoulder joint was also undertaken.

Material and methods

A group of 40 men aged 20 to 25 years ($\bar{x}$ = 21.9) was included in the study. The inclusion criteria for the study were as follows: male, aged 20–25 years, and giving voluntary informed consent to participate in the study. In addition, the criterion for inclusion in the study group was regular performance of competitive sport, i.e. volleyball for a minimum of 5 years. The inclusion criterion to the control group was no history of participation in competitive sports activities. The criteria for exclusion from the study were contraindications to the densitometry, i.e. examination with contrast agent over the last 2 days, diagnosed cancer and other chronic diseases, and additional long-term use of steroids, metabolic, anti-epileptic, psychotropic, or hormonal drugs that can affect bone metabolism. In addition, factors excluding subjects from the study were contraindications to performing a dynamometry of the upper extremities (UEs), such as UEs injuries, pain and limited range of movement of the shoulder joint (lack of ability to adopt a position in the joint specified by the examination procedure), shoulder effusion, instability of the examined joint, shoulder injuries and operations within the last 3 months, and incomplete bone union after UE fractures.

The respondents were divided into 2 groups, depending on their physical activity. The study group comprised 20 physically active men aged 20 to 25 years ($\bar{x}$ = 21.7), who practiced volleyball at the University Club of the Academic Sports Association of the University of University of Rzeszow (KU AZS UR). The control group (physically inactive group) included 20 men aged 20 to 25 years ($\bar{x}$ = 22.1), who were students of the Rzeszow. The tests were carried out once in the laboratories of the Natural and Medical Centre for Innovative Research of the Rzeszow University of Technology. The Bioethical Commission of the Medical College of Rzeszow University granted permission to conduct the research (No. 1/05.2020).

- Body composition tests were performed with the DXA method using a Lunar iDXA by GE Healthcare and analysed with Encore software. The following parameters were analysed [13, 14]:

- BMC – bone mineral content for the head (H), upper and lower extremities (U&LEs), torso (T), lumbar spine (LS1-LS4), and total body (TB), expressed in grams.
- MBF – mass of body fat for the regions as: U and LEs, T, TB, expressed in grams.
- LBM – lean body mass (consists of non-fat components such as muscles, bones, organs, blood, and water) for the areas as: U and LEs, T, and TB, expressed in grams.
- RSMI – relative skeletal muscle index, expressed as appendicular skeletal muscle mass [kg] relative to body height squared [m^2].
- RMR – resting metabolism rate, an estimate of the number of calories burned at rest and represents the minimum amount of energy needed to maintain body temperature, heart rate and ventilation, expressed as kcal/day.
- BMD – bone mineral density for the H, U and LEs, T, LS1-LS4, and TB, expressed in g/cm^2; Z-score to compare the patient's BMD to an age-matched and sex-matched reference population.
- BMI – body mass index calculated as weight/hight^2, as expressed in kg/m^2.

The Dynamometer - IDO Isometer allowed us to assess the maximal isometric strength of muscle groups acting on the shoulder joint. The tests were performed by means of a structured 10-minute warm-up for the UEs. Measurements were taken in a standing position: for flexor muscles the UE was set in a 90° flexion position (the thumb pointing at the ceiling); for abductors the UE was set in a position of 90° elevation and 30° in front of the coronal plane (the palm of the hand faced downward); for adductors and extensors the UE along the body was 0° (thumb pointing forward); in the supine position for internal and external rotators with the UE supported on the treatment table in 90° abduction, 90° elbow flexion, and a mid-forearm position. Load measurements were carried out in 2 trials – 3 s each at an interval of 30 s. The intervals between the measurements of successive muscle groups were 3 min. Each measurement was obtained in kilograms [15]. The average test result from 2 trials was converted into Newton's and then converted taking into account the length of the arm of force into the values of the moment of force (torque). The following rule was applied: the magnitude of the torque (M = Fr) [Nm] acting about a point is directly proportional to the magnitude of the acting force (F) [N] and to the distance of this point from the vector line of the force that produces the moment (the moment arm, *r*) [m] [16].

Statistical analysis

Statistical analysis was performed using Statistica 13.1 software by StatSoft. Compliance with the normality distribution of the studied variables was verified by the Shapiro-Wilk W test. Student's *t*-test evaluated differences between the size of parameters in 2 groups. Pearson's linear correlation analysis was used to assess the relationship between selected parameters from the DXA examination and the moment of force of the UE muscles. The level of statistical significance was set at $p < 0.05$.

Results

The volleyball players were statistically significantly taller (187.35 ±8.65 cm) than the men in the control group (179.55 ±7.67 cm). They presented with statistically insignificant greater body weight (83.18 ±8.71 kg vs. 81.25 ±13.78 kg) and lower BMI (23.71 ±2.21 kg/m^2 vs. 25.08 ±3.16 kg/m^2). The volleyball players had trained on average for 8.95 years, and they had performed regular physical activity for over 10 years. The subjects from the study group trained on average 4.20 days a week and 8.53 h (Table 1). The men from the control group did not train in any sport throughout their lives, occasionally attended the gym (35%), ran (5%), swam (5%), rode a bicycle (20%), or skated (10%).

Statistically significant differences were found in BMD and BMC in the U and LEs, the T, the LS1-LS4, and the TB between the volleyball player group and the control group. The control group, compared to the study group, demonstrated significantly worse results. In addition, no statistically significant differences were found for the head area in the studied groups (Table 2). It was found that the results for the Z-score were within normal limits for both groups. However, in the group of volleyball players, the values of the Z-score parameter from the DXA LS1-LS4 and TB study was statistically significantly higher (Table 2). The study did not show statistically significant dif-

Table 1. Characteristics of volleyball players' training (*N* = 20)

Parameter	$\bar{x}$	Me	Min.	Max.	SD
Training period [years]	8.95	9.50	5.00	15.00	2.65
Number of trainings/week [*N*]	4.20	3.75	2.00	9.00	1.65
Number of hours/week	8.53	8.00	4.00	18.00	3.47
Period of regular physical activity [years]	10.85	10.00	5.00	15.00	3.23

$\bar{x}$ – mean, Me – median, Min. – minimum value, Max. – maximum value, SD – standard deviation.

Table 2. Comparison of selected densitometry parameters volleyball players and inactive men

Parameter	Groups				Comparison				
	Volleyball players *N* = 20		Controls *N* = 20		Mean difference (95% CI)			Student's *t*-test	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	–95% CI	+95% CI	*t*	*P*-value
BMD [g/cm²]:									
Head	2.19	0.18	2.17	0.21	0.02	–0.10	0.15	0.39	0.699
LES	1.55	0.11	1.34	0.12	0.21	0.13	0.28	5.54*	< 0.001
Right LE	1.54	0.11	1.34	0.12	0.20	0.13	0.28	5.52*	< 0.001
Left LE	1.55	0.11	1.34	0.13	0.21	0.13	0.29	5.43*	< 0.001
UES	1.11	0.09	1.03	0.08	0.09	0.04	0.14	3.39*	0.002
Right UE	1.13	0.10	1.02	0.08	0.11	0.06	0.17	3.98*	< 0.001
Left UE	1.10	0.09	1.04	0.08	0.06	0.01	0.12	2.29*	0.027
Torso	1.24	0.10	1.07	0.11	0.17	0.10	0.23	4.93*	< 0.001
Sine	1.36	0.12	1.14	0.12	0.22	0.14	0.29	5.69*	< 0.001
Whole body	1.42	0.08	1.27	0.10	0.15	0.09	0.21	5.11*	< 0.001
BMC [g]:									
Head	543.65	56.99	534.70	66.89	8.95	–30.83	48.73	0.46	0.651
LES	1483.20	182.86	1200.20	196.25	283.00	161.58	404.42	4.72*	< 0.001
Right LE	741.90	94.03	599.80	96.71	142.10	81.04	203.16	4.71*	< 0.001
Left LE	741.40	90.34	600.55	100.38	140.85	79.72	201.98	4.66*	< 0.001
UES	516.75	64.63	458.20	73.56	58.55	14.23	102.87	2.67*	0.011
Right UE	268.15	35.75	232.65	38.28	35.50	11.79	59.21	3.03*	0.004
Left UE	248.65	31.08	225.75	35.98	22.90	1.38	44.42	2.15*	0.038
Torso	1136.55	152.66	929.25	173.11	207.30	102.82	311.78	4.02*	< 0.001
Spine	268.75	42.94	215.35	41.50	53.40	26.37	80.43	4.00*	< 0.001
Whole body	3.15	0.49	2.70	0.57	0.45	0.11	0.79	2.68*	0.011
Z-score:									
L1-L4	1.80	1.03	–0.12	0.81	1.91	1.32	2.50	6.53*	< 0.001
Whole body	1.98	0.71	0.63	0.76	1.35	0.88	1.83	5.83	< 0.001
MBF [g]:									
LES	4900.45	1404.98	5809.60	2391.92	–909.15	–2164.87	346.57	–1.47	0.151
Right LE	2463.05	705.01	2890.25	1192.04	–427.20	–1054.11	199.71	–1.38	0.176
Left LE	2437.30	704.85	2919.50	1208.29	–482.20	–1115.42	151.02	–1.54	0.131
UES	1664.10	507.24	2061.65	964.16	–397.55	–890.71	95.61	–1.63	0.111
Right UE	834.80	256.24	1042.20	483.09	–207.40	–454.94	40.14	–1.70	0.098
Left UE	829.40	254.02	1019.25	481.86	–189.85	–436.43	56.73	–1.56	0.127
Torso	7059.00	2559.41	9729.60	5157.93	–2670.60	–5277.07	–64.13	–2.07*	0.045
Whole body	14544.80	4212.34	18549.10	8378.67	–4004.30	–8249.40	240.80	–1.91	0.064

Table 2. Cont.

LBM [g]:									
LES	23125.05	2617.62	20947.25	3076.51	2177.80	349.29	4006.31	2.41*	0.021
Right LE	11696.95	1343.99	10550.15	1540.72	1146.80	221.30	2072.30	2.51*	0.017
Left LE	11428.20	1294.04	10397.05	1558.75	1031.15	114.09	1948.21	2.28*	0.029
UES	8410.30	1172.16	7879.15	1391.92	531.15	–292.58	1354.88	1.31	0.200
Right UE	4305.70	643.65	3992.45	722.41	313.25	–124.73	751.23	1.45	0.156
Left UE	4104.70	553.01	3886.65	677.26	218.05	–177.75	613.85	1.12	0.272
Torso	29884.40	3763.87	26817.65	3663.80	3066.75	689.05	5444.45	2.61*	0.013
Whole body	64889.35	7197.41	59123.10	7891.11	5766.25	931.54	10600.96	2.41*	0.021

*$\bar{x}$ – mean, SD – standard deviation, –95% CI – +95% CI confidence interval, BMD – bone mineral density, BMC – bone mineral concentration, T-score – ratio of BMD test subject to average bone density of the young person, Z-score – number of BMD standard deviations of the examined person in the same-sex and same-age population, MBF – mass of body fat, LBM – lean body mass, LES – lower extremities, LE – lower extremity, UES – upper extremities, UE – upper extremity, t Student's – t-test value, p – test probability value. *Statistically significant differences; the level of statistical significance was assumed at p < 0.05.*

ferences in MBF between the volleyball players and the control group for most parameters. A statistically significant relationship was demonstrated between the MBF of the T in the studied groups (p = 0.045). Statistically significant differences were found in the LBM parameter for both lower extremities (LES), the T and TB. The control group, compared to the group of volleyball players, showed significantly lower results (Table 2).

The studies assessed the maximal isometric torque values of selected muscle groups acting on the shoulder joint. Higher values were found in the volleyball player group compared to the control group. The above differences were statistically significant with the exception of right flexors and abductors as well as external rotators of both extremities (Table 3).

RMR values turned out to be significantly higher (p = 0.033) in the group of volleyball players ($\bar{x}$ = 1763.85, SD = 148.65) compared to the control group ($\bar{x}$ = 1631.00, SD = 184.49). There were no significant differences (p = 0.468) for RSMI; however, the parameter was higher in the volleyball players

Table 3. The mean ± SD of maximal isometric torque values [Nm] of individual muscles acting on the shoulder joint in all the examined patients and in 2 groups

Muscle group	Volleyball players (*N* = 20)		Controls (*N* = 20)		Mean difference	Student's *t*-test	
	$\bar{x}$	SD	$\bar{x}$	SD	SD	*t*	*P*-value
Flexors of UER	65.69	13.62	58.75	17.11	6.94	1.42	0.164
Flexors of UEL	67.97	11.16	58.27	16.97	9.70	2.13*	0.039
Extensors of UER	75.27	15.77	56.89	17.37	18.39	3.50*	0.001
Extensors of UEL	75.17	18.12	59.49	16.39	15.67	2.87*	0.007
Abductors of UER	67.93	13.75	60.68	16.67	7.26	1.50	0.142
Abductors of UEL	67.38	11.74	57.18	15.84	10.21	2.32*	0.026
Internal rotators of UER	30.02	7.85	24.79	6.57	5.23	2.28*	0.028
Internal rotators of UEL	29.88	7.76	24.09	6.88	5.79	2.50*	0.017
External rotators of UER	26.50	7.50	24.26	6.84	2.24	0.99	0.329
External rotators of UEL	27.64	9.36	24.56	8.65	3.08	1.08	0.286
UER total	53.08	9.96	45.07	11.65	8.01	2.34*	0.025
UEL total	53.61	10.12	44.72	11.90	8.89	2.55*	0.015
UES total	53.35	9.93	44.90	11.67	8.45	2.47*	0.018

*Nm – newton metre, $\bar{x}$ – mean, SD – standard deviation, UES – upper extremities, UEL – left upper extremity, UER – right upper extremity, t – student t-test value, p – test probability value. *Statistically significant differences; the level of statistical significance was assumed at p < 0.05.*

Table 4. Comparison of the RMR and RSMI values between volleyball players and inactive men

Parameters	Groups				Comparison				
	Volleyball players (N = 20)		Controls (N = 20)		Mean difference (95% CI)			Student's t-test	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	–95% CI	+95% CI	t	P-value
RMR	1763.85	148.65	1631.00	184.49	132.85	11.51	254.19	2.24*	0.033
RSMI	8.98	0.84	8.76	0.86	0.23	-0.41	0.86	0.73	0.468

*$\bar{x}$ – mean, SD – standard deviation, –95% CI – +95% CI confidence interval, RMR – resting metabolic rate, RSMI – resting skeletal muscle index, t – Student's t-test value, p – test probability value. *Statistically significant differences; the level of statistical significance was assumed at $p < 0.05$.*

Table 5. The relationship between BMD, BMC, MBF, and LBM and the moment of force of the upper extremities muscles in all subjects (N = 40)

Variable	r	P-value
BMD and the moment of power of the muscles of the upper extremities:		
BMD UER and the moment of force of UER	0.46*	0.003
BMD UEL and the moment of force of UEL	0.46*	0.003
BMD UES and the moment of force of UES	0.50*	0.001
BMD Total and the moment of force of UES	0.51*	0.001
BMC and the moment of force of the muscles of the upper extremities:		
BMC UER and the moment of force of UER	0.55*	< 0.001
BMC UEL and the moment of force of UEL	0.47*	0.002
BMC UES and the moment of force of UES	0.52*	0.001
BMC Total and the moment of force of UES	0.49*	0.001
MBF and the moment of force of the muscles of the upper extremities:		
MBF UER and the moment of force of UER	–0.26	0.111
MBF UEL and the moment of force of UEL	–0.25	0.114
MBF UES and the moment of force of UES	–0.26	0.105
MBF Total and the moment of force of UES	–0.26	0.106
LBM and the moment of force of the muscles of the upper extremities:		
LBM UER and the moment of force of UER	0.66*	< 0.001
LBM UEL and the moment of force of UEL	0.58*	< 0.001
LBM UES and the moment of force of UES	0.43*	0.006
LBM Total and the moment of force of UES	0.61*	< 0.001

*BMD – bone mineral density, BMC – bone mineral concentration, MBF – mass of body fat, LBM – lean body mass of soft tissue, UEL – left upper extremity, UER – right upper extremity, UES – upper extremities, r – Pearson's linear correlation value, p – test probability value. *Statistically significant differences; the level of statistical significance was assumed at $p < 0.05$.*

group ($\bar{x}$ = 8.98, SD = 0.84) than in the control group ($\bar{x}$ = 8.76, SD = 0.86) (Table 4).

The results of our study (N = 40) showed statistically significant, linear relationships between the moment of force of upper extremities (UE) and their BMD, BMC, and LBM. Higher BMC, BMD, and LBM values were positively correlated with a higher moment of force. There was no statistically significant linear relationship between the moment of force of the UE and MBF ($p > 0.05$) (Table 5).

Discussion

The study of volleyball players may help to reveal the relationships between physical activity and the specific changes induced in different skeletal regions or in body composition.

The studied volleyball players were more often characterized by higher BMD and BMC than men in the control group. Significant differences in values were shown regardless of the body part being analysed, except for the head. Reuter *et al.* examined two mixed-sex groups: medical students and students of physical education, respectively. The results showed that the BMD parameter for the proximal femur and for the whole body determined by the Z-score was significantly higher among students of physical education. Considering the lumbar spine, a statistically significant difference was shown only in the case of men [17]. In the meta-analysis of Arasheben *et al.* it was shown that higher BMD values can be observed among athletes with a high level of competition compared to physically active people with a low level of competition. Peak bone mass is achieved at between 20 and 30 years of age [18]. Sports activity at this age can lead to changes that improve bone architecture by increasing BMC and BMD [9, 19–21]. Strength-based and high-impact sports appear to be associated with higher BMD while unloaded exercise such as swimming has no impact on bone mass [22]. In the study of Valente-dos-Santos *et al.* the goal was to compare BMC and BMD among young swimmers and volleyball players. The results showed higher BMD values among the volleyball player group compared to the group practicing swimming. However, the difference in lean body mass between the groups was small [23]. In the study by Andersen *et al.* comparing BMD in Norwegian elite road cyclists with medium- and long-distance runners, BMD differences were confirmed depending on the sport. The studies showed that half of the group of cyclists had reduced BMD values determined using the *Z*-score index. The reason for such results may be the specificity of sport of cycling and the desire to attain the most speed at the expense of body weight. In addition, one should bear in mind that the skeleton is not subjected to forces generated during contact with the ground [24]. Moraes *et al.* compared BMD and BMC between university athletes with a mean age of 22.37 ±3.71 years from different sports. They identified in female groups that volleyball players presented with higher lumbar BMD values compared to judo athletes, and lumbar BMC values of indoor soccer athletes was higher compared to judo athletes [25]. Considering the positive impact of sport on skeletal development, one can find information that effort with shorter, more intense characteristics will have a greater impact on bone development [26]. In addition, effort characterized by a large number of jumps during a training session can have a positive effect on the BMC within the hip [27]. This is also supported by the results of this study because the value of the *Z*-score parameter (LS1-LS4 and TB) among volleyball players was statistically significantly higher than the control group. Sports such as volleyball can be considered as activities that have a beneficial effect on changes in the skeletal system during regular workouts. High frequency of stimuli such as repetitive jumps, lateral movements, and hitting/receiving the ball are stimuli generating a high voltage, affecting the skeletal system. In addition, it has been proven that the impulse in the form of many repetitive jumps per unit of time is more beneficial for bone development than single maximum jumps. Moreover, periodic application of a training protocol based on jumping can have a positive effect on improving bone structure in athletes undertaking physical activities such as swimming and cycling [17, 26, 28, 29].

In our study, we also analysed the mass body fat (MBF) and lean body mass of soft tissue (LBM). The volleyball players showed a lower MBF and a higher LBM compared to the inactive men. The difference regarding the trunk was statistically significant in the case of MBF. In turn, statistically significant differences regarding LBM were shown in the case of right and left lower extremities, torso, and whole body. However, the values given seem obvious because body composition, with a properly balanced diet, is subject to individual changes, especially in the context of physical activity and sport. From a biological point of view, changes in body composition do not only concern weight, but also factors such as lean body mass, fat mass, total body water and the elements contained in it, and bone density [30]. An important role is played here by the metabolism, which is associated with the level of physical activity [31]. With a decrease in activity, there is a decrease in muscle mass, an increase in body fat, decalcification of the skeletal system, or a slowdown in the metabolism. In addition, regular practicing of sports causes the peripheral tissues of the human body to become sensitive to insulin, leading to fat mass reduction [32]. This is confirmed by the results of our study, in which higher body fat mass and lower muscle mass were found in people physically inactive in comparison to volleyball players. In addition, Nilsson *et al.* in their studies showed that in inactive people, lean body mass is lower, and the amount of body fat is at a higher level compared to active people, such as footballers and athletes who perform resistance training [8]. In the study by Reuter *et al.* the values of MBF and LBM in medical students (assumed as inactive people) were compared with those in physical education students (active group). Regardless of gender, the percentage of body fat was higher in medical students, while lean body mass was lower in them [17]. Taking into account swimmers and volleyball players, according to the research by Valente-dos-Santos *et al.*, the body weight of swimmers was 6 kg lower. In turn, fat-free body mass of soft tissue was lower by only 0.1 kg. A significant difference was seen in the fat mass, which was lower in the swimmers by as much as 5.2 kg [23]. Agostinete *et al.* identified the differences in soft tissue profiles in 10 different loading sports. The comparisons among groups of adolescent athletes showed that the highest value of MBF was observed in baseball players, followed by those practicing kung-fu, volleyball, judo, swimming, basketball, karate, track and field, and football, while the lowest was seen in gymnasts. They also showed that soccer players had the highest LBM, followed by practicing track and field, basketball, swimming, gymnastics, judo, kung-fu, karate, and volleyball, and the lowest lean body mass was found in baseball players [33].

Optimizing the energy supply in the diet is crucial for the proper nutrition of athletes. A successful diet of volleyball players requires careful consideration of daily energy expenditure. To determine the individual energy requirements for a given athlete, it is important to estimate the RMR. This parameter affects the total energy expenditure, and thus the energy balance. Research Czeck *et al.*, in a group of 18 developing elite rugby union athletes (age 20.2 ±1.7 years) from the USA, showed a resting metabolic rate of 2389 ±263 kcal/day. RMR values were higher among US rugby players compared to the volleyball players we studied, in whom the average RMR value was 1764 ±149 kcal/day [34]. The resting metabolic rate was significantly lower in the control group, at 1631 ±184 kcal/day. Śliwiński *et al.* found a lower resting metabolic rate of 1443 ±199 kcal/day in people regularly participating in strength and endurance training at the gym. The differences probably resulted from the selection of the study sample – in the studies of Śliwiński *et al.* the majority were women (79 women and 11 men) and the average age of the respondents was higher and amounted to 44.76 years (range: 50–40). In addition, the resting metabolic rate was assessed using the electrical impedance method on an InBody 170-MED Fitness device [35]. In this study, the RSMI parameter was also estimated, which represents the relative amount of muscle in the arms and legs compared to height. This parameter had a higher average value in the group of volleyball players (8.98 ±0.84 kg/m^2) than in the control group (8.76 ±0.86 kg/m^2). The study conducted in Poland by Trinschek *et al.* showed slightly lower values of the RSMI parameter in the group of endurance athletes: long-distance runners and triathletes (N = 10; age 25.3 ±5.3 years) at the level of 8.5 ±0.6 kg/m^2. On the other hand, sprinters (N = 12; specialized in the distances of 100 and 200 m; age 24.7 ±3.3 years) had a higher RSMI score of 9.6 ±0.6 kg/m^2. The control group consisted of 10 healthy recreationally active men (age 29 ±4.5 years) with an RSMI of 9.0 ±0.6 kg/m^2 [36].

In our study we analysed the maximal isometric torque values of the shoulder muscle obtained by volleyball players and a control group, and we revealed significant differences. The volleyball players showed higher values, and most of the differences were statistically significant. Our studies also showed significant and positive relationships between BMD, BMC, and LBM and the maximal isometric torque values of the shoulder muscle. Similar results were shown by Alfredson *et al.*, i.e. that female volleyball players had a higher concentric and eccentric strength in the rotator muscles of the shoulder and in the extensor muscles of the elbow compared to untrained controls [37]. Mersmann *et al.* showed greater knee extensor strength in 21 adolescent volleyball athletes compared to 24 untrained similar-aged controls [38]. Michalski and Lipińska, looking for differences in muscle strength in players practicing beach volleyball and volleyball, did not find significant differences between the groups [39]. Hadzic *et al.* observed significant differences in concentric and eccentric strength of quadriceps and hamstring muscles of 95 male professional volleyball players with respect to playing level. The function of these muscles was independent of the players' age and playing position. They also showed that there were no signs of bilateral strength asymmetry regardless of the muscle group tested and contraction mode [40].

DXA is currently widely used in assessing bone mineral density and content and soft-tissue composition. Our study, however, seems to be one of the first to assess the composition of the UEs in connection with the assessment of their muscle strength. The limitation of the study is the small sample size, which cannot be referred to the population of young people. The current study also did not include assessment of the strength of the T and LEs muscles in volleyball players, which will be the subject of future research.

Conclusions

The physical activity typical for volleyball training and competitions is associated with high BMD and BMC values for the upper and lower extremities, torso, lumbar spine, and whole body of volleyball players. A high, competitive level of activity resulted in lower MBF and higher LBM in the torso, lower extremities, and whole body. We also observe higher BMD and BMC and greater LBM of the upper extremities in men with greater shoulder muscle strength. Our study highlights the importance of dynamic loading on different skeletal regions and the systematic development of muscle strength to increase BMD and BMC. Therefore, volleyball-specific training exercises would benefit the muscle strength and bone mass of competing athletes.

Conflict of interest

The authors declare no conflict of interest.

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