RESEARCH ARTICLE

Bone Mineral Density and Content among Iranian Elite Male Athletes in Different Sports

Behrooz **Imeri**, PhD [1]; Mehdi **Gheitasi**, PhD [2]; Arash **Khaledi**, PhD[3]; Esmaeil **Mozafaripour**, PhD[4]

Research performed at the Golestan Qaboos Medicine Radiology Center, Gonbad Kavous University, Gonbad Kavous, Iran

Received: 13 August 2022 *Accepted: 30 November 2022*

Abstract

Objectives: Sport is one of the best ways to prevent osteoporosis; however, not all sports have the same impact on bones, for instance, swimming (SW) may have no effect or be harmful. Elite athletes are the best choice to detect the effects of any sport. Thus, this study was conducted firstly to compare the bone mineral density (BMD) and bone mineral content (BMC) of elite athletes in volleyball (VB), basketball (BB), and long-distance running (LR) together, and secondly to compare those corresponding values in SW athletes with those of non-athletes (NA).

Methods: The subjects (n=58) of this cross-sectional study included elite male athletes (members of Iran's national teams, with a minimum of 12-15 hours of training per week) and NA (control; C) who were divided into BB, VB, LR, SW (n=12 for each), and C (n=10) groups. The DEXA scan measured the amount of BMD and BMC values in the lumbar spine (LS; L2-L4) and proximal femur (PF; neck, trochanter, and Ward's triangle) areas.

Results: In the LS areas, LR had significantly higher BMD than the BB, VB, SW, and C groups (P<0.001), while for BMC, both LR and VB were significantly superior to other groups (P<0.001). Moreover, the BMD and BMC of the PF areas of VB and BB were significantly higher than those of the LR, SW, and C groups (P<0.001). Finally, in all areas, SW showed significantly higher BMD and BMC, compared to the C group (except for trochanter and femur neck BMC) (P<0.05).

Conclusion: LR athletes showed the most bone acquisition in the LS areas and VB players in the PF areas, while BB players ranked third in osteoporosis prevention in the mentioned regions. Unexpectedly, SW athletes also had better BMD and BMC than NA; therefore, after weight-bearing sports, this type of sport can be effective in bone acquisition.

Level of evidence: III

Keywords: Basketball, Bone mineral density, Elite athletes, Osteoporosis, Running, Swimming, Volleyball

Introduction

Osteoporosis is a destructive disease in the skeletal structure. It is considered the fourth enemy of humanity after a heart attack, stroke, and cancer, especially in old age.[1] It is usually silent, which means that a person does not notice any symptoms before a bone density test or fragility fractures.[2,3] The highest rate of fractures caused by osteoporosis occurs in the areas of the lumbar spine (LS; 42%) and proximal femur (PF; 30%).4 According to the World Health Organization, the population with this deadly disease will increase by 23% from 2010 to 2025 (27.5 to 33.9 million).[5,6] Preventive strategies in adolescence and young age are the key to fighting against this disease in old age.[7,8] Although genetic factors can explain up to 60%-80% of the etiology for bone mineral density (BMD) and bone mineral content (BMC) ranges, the remaining 20%-40% can be modified by environmental factors, such as physical activity.[9] According to Wolf's law, applying different loads over a long period improves and adapts bone tissue.[10] Thus, the role of varying sports loads in stimulating bone remodeling is

Corresponding Author: Behrooz IMERI, Department of Sport Sciences, Faculty of Human Sciences and Sport Sciences, University of Gonbadekavoos, Gonbadekavoos, Iran

Email: behrooz.imeri@gmail.com

irrefutable.[11-13] Typically, sports are divided into two categories: weight-bearing11 and non-weight bearing,12 and the former is the best choice for improving bone health.[11-13], Nevertheless, this category of sports is not suitable and favorable for everyone.[12] For example, athletes at risk for osteoporosis, apart from the risk of fracture, are also usually at risk for cardiovascular and cerebrovascular diseases. High-intensity sports are also harmful to these athletes.[12, 14] As a result, swimming as a popular sport, in addition to many therapeutic benefits, can be the best option and cannot be ignored.[12, 15]

Despite extensive studies, there is still equivocal evidence as to which weight-bearing sport can best stimulate the two critical areas at risk for osteoporotic fractures (LS and PF).[16] Additionally, it is still unclear whether swimming is effective or neutral in bone growth.[5,12]

Depending on its kinetic and kinematic parameters, each sport has different effects on each area of the skeletal system.[17] Considering that professional athletes are engaged in their sports for many hours during adolescence and youth, they can be of greater help in identifying the bone tissue areas in which each sport has resulted in better bone acquisition.5 Therefore, various sports with various loads were chosen (odd-impact, high-impact, repetitive low-impact, and non-impact exercise loadings). To achieve more accurate results, only male athletes were considered since the bone acquisition in males and females may be different.[4, 18]

Since access to elite athletes is very limited and difficult, most studies in the literature were conducted either on recreational or on semi-professional athletes.[19-21] Furthermore, at the time of writing this manuscript, no study has examined elite male athletes in terms of the bone status of basketball, volleyball, and running together, and swimmers with non-athletes. Hence, conducting the present study was necessary to answer the following questions:

Q1. Which of the weight-bearing sports is more effective in improving bone mass?

Q2. Do swimmers have more bone density than non-athletes?

Q3. Which of the two high-risk fracture areas (LS and PF) can acquire more bone by performing these sports?

Therefore, the primary aim of this study was to compare the bone mineral density (BMD) and bone mineral content (BMC) of elite male athletes of basketball, volleyball, and long-distance running together. The secondary aim was to compare swimmers with non-athletes in the two areas of the PF and LS. Based on previous research, [22] it can be assumed that swimming is neutral or ineffective, and basketball causes more bone acquisition than other sports.[11]

Materials and Methods

Design

This cross-sectional study compared the effect of different sports on the BMD and BMC values of elite athletes. The study protocol was approved by the Ethics Committee of the Research Institute of Sports Sciences in Tehran, Iran, based on the Declaration of Helsinki 2018.[23]

Participants

The participants (n=58) in this study included 48 elite male athletes (who were members of Iranian national teams) as the experimental groups and 10 non-athletes (NA) as the control (C) group. The athletes enrolled voluntarily for the study and were purposefully divided into basketball (BB), volleyball (VB), long-distance running (LR), and swimming (SW) (n=12 for each). In addition, informed consent was obtained from all participants. To determine the sample size, G Power software (3.1.9.2 Freeware.

University of Dusseldorf, Dusseldorf, Germany) based on repeated measures analysis of variance test with a statistical power of 80% and significance level of 0.05 was used.[24]

Inclusion criteria

The male athletes were over 19 years of age, with at least eight years of practice in their sports specialty, at least three years of experience in high-level competition sport, and a minimum of 12-15 hours of training per week, as well as competing at national or international championships and games.[5, 25]

Exclusion criteria

The exclusion criteria were hypo or hyperthyroidism, diabetes, kidney failure, liver failure, respiratory or heart diseases, as well as smoking or consuming alcohol.[5, 26] Furthermore, the athletes who had any acute musculoskeletal injuries were excluded since they quit the sport due to their acute injury (for at least six months) and took drugs that affect BMD and BMC (e.g., testosterone, corticosteroids).[25]

Instruments

The height and weight of the subjects were measured by a height meter and an analog scale with a sensitivity of 0.1 kg. Then, their body mass index (BMI) was calculated using the mass (kg)/ height (m) ^{2} formula. In addition, a DEXA scan was conducted (Hologic Series Discovery QDR, Software Physician's Viewer, APEX System Software Version 3.1.2. Bedford, MA, USA) for measuring the subjects' BMD (g/cm2) and BMC (g) in the areas of LS (L2-L4) and PF (femur neck, trochanter and Ward's triangle) [Fig. 1]. DEXA scan is very accurate and the gold standard method for bone density measurement.[27] Bone density refers to the amount of bone material in a square centimeter of bone, where the denser tissue allows less radiation to pass. In fact, more compressed bone is stronger and less prone to fracture.[27]

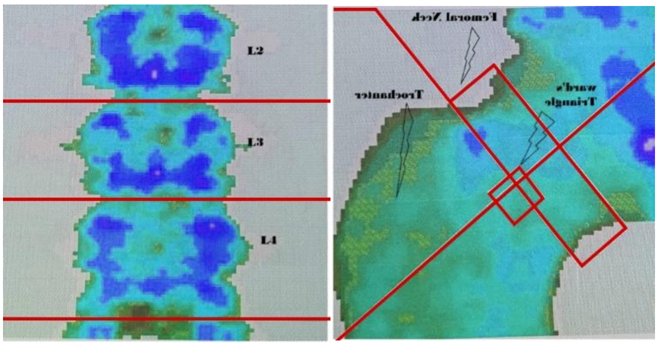

Fig1. The measurement of BMD and BMC in Lumbar spine (L2- L4) and femur (neck, trochanter and ward's triangle) areas by DEXA

Statistical analysis

The statistical analysis was performed using SPSS software (version 19.0, SPSS Inc., Chicago, IL), in which the data were checked for normality distribution. One-way ANOVA was used to detect the differences among groups. ANCOVA was applied to compare the amount of BMD and BMC, which were adjusted for height, weight, body fat percentage (BF%), and age among the five groups. Finally, the Bonferroni post-hoc test was used to compare the means, and the significance level was set at P≤0.05.

Results

The demographic characteristics of the subjects are shown in Table 1. As displayed, kurtosis and skewness for the variables ranged between -1 and +1, which indicated the normal distribution of the data. Therefore, parametric methods were used for data analysis. Levene's test was performed, and the test assumptions were met. The results of one-way ANOVA indicated a significant difference in the mean number of groups, while each group was compared using Scheffe's method for the post-hoc test [Table 1].

Table 1. Demographic characteristics of the subjects

Groups	N	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m2)	Body Fat (%)
Basketball	12	20.08± 0.90 bcde	90.96± 6.23 cde	196.79± 4.11	23.49± 1.62	13.90± 1.79 bcde
Running	12	22.17± 1.34 e	73.75± 3.17 c	180.58± 3.18 ade	22.63± 1.22	16.06± 1.32 c
Swimming	12	22.83± 1.34 e	83.17± 8.36	184.50± 5.28 a	24.36± 1.10	18.28± 1.40 d
Volleyball	12	23.00± 0.74	81.25± 4.75	190.00± 5.20	22.50± 0.93	16.09± 0.97
Control	10	24.40± 0.97	80.60± 8.87	187.00± 4.94	23.02± 2.13	17.04± 2.45

BMI: Body Mass Index; Values are mean± SD
A: P≤0.05 (significant difference among basketball players)
B: P≤0.05 (significant difference among runners)
C: P≤0.05 (significant difference among swimmers)
D: P≤0.05 (significant difference among volleyball players)
E: P≤0.05 (significant difference among the control group)

Methods were used for data analysis. Levene's test was performed, and the test assumptions were met. The results of one-way ANOVA indicated a significant difference in the mean number of groups, while each group was compared using Scheffe's method for the post-hoc test [Table 1].

The results of ANCOVA indicated a significant difference between the BMD means of LS (F[4, 49]=18.24, P<0.001), femur neck (F[4, 49]=79.05, P<0.001), trochanter (F[4, 49]=42.70, P<0.001) and Ward's triangle (F[4, 49]=79.99, P<0.001), and the BMC means of LS (F[4, 49]=31.85, P<0.001), femur neck (F[4, 49]=27.08, P<0.001), trochanter (F[4, 49]=14.40, P<0.001) and Ward's triangle (F[4, 49]=426.88, P<0.001) [Table 2].

As shown in Table 2, the BMD for LS areas was significantly higher in the LR group, compared to the BB, VB, SW and C groups, in that order (P<0.001). In addition, the femur neck BMD in the C group was significantly lower than that in all sports groups, and it was significantly lower in the LR group than in the BB and VB groups, in that order (P<0.05). Furthermore, the trochanter BMD in all sports groups was significantly higher than that in the C group. At the same time, it was significantly higher in the BB group than in the VB and LR groups in descending order (P<0.001). Regarding the results of Ward's triangle BMD, the C group had a significantly lower amount of BMD, compared to the other groups, and it was significantly higher in the VB group than in the other sports groups (P<0.001). Finally, the BB group had a higher BMD mean than the LR group (P<0.001) [Table 2].

Regarding the results of the BMC, the LS areas of the LR and VB groups had significantly higher means than the other groups, and the BMC was significantly higher in the SW group than in the C group (P<0.001). Although the femur neck BMC in the VB group was significantly higher than that of the other groups (P<0.05), the amount in the LR group was significantly higher than that in the SW and C groups (P<0.001). In addition, the trochanter BMC of the BB and VB groups was significantly higher than those of the LR, while LR had a higher amount than the SW and C groups (P<0.05). Regarding Ward's triangle BMC, the BB group showed a higher amount than the other groups, and it was significantly higher than that of the VB group, compared to the LR, SW, and C groups, in that order (P<0.001). Furthermore, LR had a significantly higher amount than the SW and C groups. Finally, the amount was significantly higher in SW than in the C group (P<0.001) [Table 2].

Table 2. The adjusted BMD and BMC in the groups

Variables	Basketball	Volleyball	Running	Swimming	Control
BMD Lumbar Spine	1.33± 0.04	1.32± 0.03	1.37± 0.03	1.18± 0.03 bd	1.09± 0.03 abd
BMD Femur Neck	1.47± 0.03	1.45± 0.02	1.35± 0.02 D	1.07± 0.02 abd	0.95± 0.03 abcd
BMD Trochanter	1.16± 0.05	1.23± 0.03	1.18± 0.03	0.86± 0.03 abd	0.81± 0.04 abd
BMD Ward's Triangle	1.24± 0.04	1.36± 0.03	1.17± 0.02 d	0.93± 0.03 abd	0.74± 0.03 abcd
BMC Lumbar spine	60.62± 2.71 d	75.39± 1.66	74.24± 1.56	60.63± 1.76 abd	57.46± 2.18 bd
BMC Femur Neck	7.06± 0.39 d	8.84± 0.24	7.69± 0.23 D	5.95± 0.25 bd	6.03± 0.32 bd
BMC Trochanter	17.85± 0.84	16.42± 0.52	15.70± 0.49	11.30± 0.55 abd	13.50± 0.68 AD
BMC Ward's Triangle	3.47± 0.50	1.37± 0.03 a	1.16± 0.03 ad	0.91± 0.03 abd	0.72± 0.04 abcd

The results of Bonferroni post-hoc test for BMD (Bone Mineral Density) and BMC (Bone Mineral Content).
a. *P≤0.05* (A significant difference with basketball players, respectively)
b. *P≤0.05* (A significant difference with runners, respectively)
c. *P≤0.05* (A significant difference with swimmers, respectively)
d. *P≤0.05* (A significant difference with volleyball players, respectively)
e. *P≤0.05* (A significant difference with controls, respectively)

Discussion

This study compared BMD and BMC among elite male athletes of BB, VB, and LR, and then SW with NA. It was hypothesized that among weight-bearing sports, BB causes more bone acquisition than other sports, [11] and SW is neutral or ineffective at improving BMD and BMC.[22] However, the findings of the present study do not support the above hypotheses. This study found that LR (especially in the LS areas), VB (especially in the PF areas), and BB are the first, second, and third osteogenic sports, respectively. Additionally, this study found that SW athletes had better BMD and BMC than NA and were ranked fourth after weight-bearing sports.

Therefore, all the athletes had a higher BMD and BMC in the two most susceptible fracture sites (LS and PF) caused by osteoporosis than NA.4 In the following, details of the findings are discussed and several new aspects are touched on which can add to the literature. Additionally, since the majority of the research in this field was conducted on non-elite athletes, these studies have also been discussed.[11]

Contrary to the findings of several researchers and even a systematic review,[22] in which SW was introduced as an ineffective or neutral sport for bone health,[20,22,28] the SW athletes in this study showed higher BMD and BMC than NA. Nonetheless, many details can be effective in improving BMD and BMC in this sport, such as movement pattern (freestyle, butterfly, etc.), type (speed or endurance), and training period length, but the most important possible reason for the contradiction of the findings of this study with previous findings can be attributed to the inclusion of professional SW athletes.[15]

Indeed, two recent studies have been conducted with similar findings to the present study.[5,15] Moreover, a recent systematic review and meta-analysis by Su Y et al. (2020) reported that SW athletes who have long training periods in a week (3 to 6 hours or even longer) have better BMD than those who have short periods (less than 3 hours a week), which can be consistent with our findings.[12] However, research on professional SW athletes is very limited, and decisions cannot be made with certainty about this issue.[5,12,15]

Regardless of the scientific issue related to the investigation of the effectiveness of SW as a non-weight-bearing sport, this research aimed to compare the effect of weight-bearing sports on two key areas (LS and PF), which are prone to fractures by osteopenia and osteoporosis.[2,4] Contrary to several previous studies, the BB players in the present research did not rank first in gaining bone density among the players of the other weight-bearing sports.[11,15,29,30] Stojanović et al. (2020), in a systematic review and meta-analysis, compared football, VB, BB, and SW with NA and stated that BB players have higher BMD than other athletes, especially in the femur and hip areas due to repeated jumping.[11]

Nevertheless, it is noteworthy that in the PF areas, the BB players in the present study ranked second with a very small average difference, compared to the VB players, and even in the femur neck BMD, Ward's triangle and trochanter BMC values, they had more bone acquisition than the VB and LR athletes. Therefore, taking these findings into account, the results of the present study are approximately aligned with the above systematic review.[11] In another study by Zouch et al., the bone mass in the whole body, LS, and total hip areas were directly compared among VB, BB, and NA. In their investigated areas, apart from the fact that VB and BB were introduced as osteogenic sports, in general, the VB players had better bone status in the PF areas, which is in line with the findings of the current study.[31] One of the most important reasons for the non-contradictory results of these researchers can be attributed to gender (only male subjects). Due to different anatomical structures in males and females, especially in the pelvic-femoral areas, the mechanical load and stress applied in each area of the skeletal structure can also be different.[32]

Regarding the LS regions, LR athletes were superior to VB and BB players. This finding is consistent with the results of a recent study conducted in 2022, which reported that long-term applied loads in LR cause an increase in bone resorption, which is associated with a corresponding increase in bone matrix deposition. This study also stated that the most important factor that causes a decrease in BMD in these athletes is the lack of proper recovery after training.[33]

In a contradictory study, gymnastics, crew, softball, running, field hockey, cross-country, soccer, and SW athletes were compared, and it was found that runners (except for average leg score) and SW athletes showed the lowest BMD in the pelvic, lumbar, and total body areas.[34] Nevertheless, in addition to the fact that these researchers only investigated female athletes, most of their runners had menstrual dysfunction (44.0%). Apart from this, the lack of uniformity in the type of runners' training (track and cross-country runners by events of 800 m) is also a possible influential factor that should be considered.[34,35] All the above contradictions are gaps that require the attention of researchers in the future to provide a more definitive answer.

Nevertheless, there are some important reasons for changes in the bone tissue of the LS and PF regions in weight-bearing athletes, which are necessary to consider. For example, BB and VB athletes mainly perform activities on hardwood surfaces, which causes the lower limbs, especially the PF areas and the spine, to be under tremendous pressure and stress. In addition, the dominant and common movements of these athletes include frequent jumps and sudden changes of direction, with the difference that VB players make longer jumps than BB players.[11,36,37] In contrast, LR athletes, by performing repeated movements on almost flexible surfaces without sudden changes of direction and jumping, maintain their center of gravity towards the front of the body near the lumbopelvic region for a long time, which probably leads to more pressure and stress tolerance in the LS than PF areas.[33,38]

The present study had several strengths, the first of which was the selection of elite athletes to diagnose the effects of each sport on bone indices more accurately, considering that they trained regularly and with high intensity, frequency, and volume. The second strength was choosing only elite male athletes, which was done for two reasons. The first reason for this decision was differences in hormonal mechanisms. The second reason was the different anatomical and skeletal structures between male and female athletes, which can be effective in bone acquisition.[4,11,32] The third strong point in this study was choosing sports with different loads (high-impact, odd-impact, repetitive low-impact, and non-impact exercise loadings) due to the more comprehensive diagnosis of each training style on bone growth.

The present study also had several limitations. The first was access to a small sample size due to the limited number of elite athletes. The second limitation was that it had a cross-sectional design because it only estimated and limited the probability of showing causality without the possibility of a follow-up period. Finally, the third limitation was in terms of constraints in controlling the athletes' nutritional status and consumption of vitamin supplements, such as calcium and vitamin D.[39] Thus, it is strongly suggested that future researchers evaluate the elite athletes of other popular sports, such as football, in addition to considering the limitations mentioned above.

Conclusion

In summary, LR athletes had the highest BMD in the LS regions, followed by BB and VB players, while LR and VB athletes had almost similar and higher BMC than BB players. In the PF areas, VB (especially BMD) and BB players (especially BMC) ranked higher than LR athletes in bone acquisition. Unexpectedly, SW athletes also showed better BMD and BMC in all mentioned areas than NA (except for trochanter and femur neck BMC). Therefore, in a general ranking, LR, VB, and finally BB ranked first, second, and third, respectively, as osteogenic sports. Additionally, SW can also be effective in the bone acquisition and preventing osteopenia and osteoporosis after weight-bearing sports.

Acknowledgement

The authors would like to express their gratitude to all the participants.

Conflict of interest: There is no conflict of interest in this study.

Funding: The authors received NO financial support for the preparation, research, authorship, and publication of this manuscript.

Behrooz Imeri PhD [1]
Mehdi Gheitasi PhD [2]
Arash Khaledi PhD[3]
Esmaeil Mozafaripour PhD[4]
1 Department of Sport Sciences, Faculty of Human Sciences and Sport Sciences, University of Gonbadekavoos, Gonbadekavoos, Iran
2 Department of Health & Sport Rehabilitation, Faculty of Sport Science & Health, University of Shahid Beheshti, Tehran, Iran
3 Department of Sport Sciences, Kish International Campus, University of Tehran, Kish, Iran
4 Department, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran

REFERENCES

1. Lane NE. Epidemiology, etiology, and diagnosis of osteoporosis. Am J Obstet Gynecol. 2006; 194(2):S3-S11. doi: 10.1016/j.ajog.2005.08.047.
2. Johnell O, Kanis J. An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. Osteoporos Int. 2006; 17(12):1726-1733. doi: 10.1007/s00198-006-0172-4.
3. Rinonapoli G, Ruggiero C, Meccariello L, Bisaccia M, Ceccarini P, Caraffa A. Osteoporosis in men: a review of an underestimated bone condition. Int J Mol Sci. 2021; 22(4):2105. doi: 10.3390/ijms22042105.
4. Nieves JW. Sex-differences in skeletal growth and aging. Curr Osteoporos Rep. 2017; 15(2):70-75. doi: 10.1007/s11914-017-0349-0.
5. Bellver M, Del Rio L, Jovell E, Drobnic F, Trilla A. Bone mineral density and bone mineral content among female elite athletes. Bone. 2019; 127:393-400. doi: 10.1016/j.bone.2019.06.030.
6. Hernlund E, Svedbom A, Ivergård M, et al. Osteoporosis in the European Union: medical management, epidemiology and economic burden. Arch Osteoporos. 2013; 8(1):1-115. doi: 10.1007/s11657-013-0136-1.
7. Karlsson M, Nordqvist A, Karlsson C. Physical activity increases bone mass during growth. Food Nutr Res. 2008;52(1):1871. doi: 10.3402/fnr.v52i0.1871.
8. Vlachopoulos D, Ubago-Guisado E, Barker AR, et al. Determinants of bone outcomes in adolescent athletes at baseline: the PRO-BONE study. Med Sci Sports Exerc. 2017;49(7):1389-1396. doi: 10.1249/MSS.0000000000001233.
9. Dhonukshe-Rutten RA, Lips M, de Jong N, et al. Vitamin B-12 status is associated with bone mineral content and bone mineral density in frail elderly women but not in men. J Nutr. 2003; 133(3):801-807. doi: 10.1093/jn/133.3.801.
10. Frost HM. A 2003 update of bone physiology and Wolff's Law for clinicians. Angle Orthod. 2004; 74(1):3-15. doi: 10.1043/0003-3219(2004)074<0003:AUOBPA>2.0.CO;2.
11. Stojanović E, Radovanović D, Dalbo VJ, et al. Basketball players possess a higher bone mineral density than matched non-athletes, swimming, soccer, and volleyball athletes: a systematic review and meta-analysis. Arch Osteoporos. 2020; 15(1):1-21. doi: 10.1007/s11657-020-00803-7.
12. Su Y, Chen Z, Xie W. Swimming as Treatment for Osteoporosis: A Systematic Review and Meta-analysis. Biomed Res Int. 2020; 2020:6210201. doi: 10.1155/2020/6210201.
13. James M-S, Carroll S. Effects of different impact exercise modalities on bone mineral density in premenopausal women: a meta-analysis. J Bone Miner Metab. 2010; 28(3):251-267. doi: 10.1007/s00774-009-0139-6.
14. FitzGerald L, Carpenter C. Bone mineral density results influencing health-related behaviors in male athletes at risk for osteoporosis. J Clin Densitom. 2010; 13(3):256-262. doi: 10.1016/j.jocd.2010.05.004.
15. Gheitasi M, Imeri B, Khaledi A, Mozafaripour E. The Effect of Professional Sports Participation on Bone Content and Density in Elite Female Athletes. Research Article. 2022; 13(2):e119683. doi:10.5812/asjsm-119683.

16. Hind K, Burrows M. Weight-bearing exercise and bone mineral accrual in children and adolescents: a review of controlled trials. Bone. 2007; 40(1):14-27. doi: 10.1016/j.bone.2006.07.006.

17. Heinonen A, Oja P, Kannus P, et al. Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. Bone. 1995;17(3):197-203. doi: 10.1016/8756-3282(95)00151-3.
18. Baker BS, Chen Z, Larson RD, Bemben MG, Bemben DA. Sex differences in bone density, geometry, and bone strength of competitive soccer players. J Musculoskelet Neuronal Interact. 2020;20(1):62-76.
19. Tenforde AS, Carlson JL, Sainani KL, et al. Sport and triad risk factors influence bone mineral density in collegiate athletes. Med Sci Sports Exerc. 2018;50(12):2536-2543. doi: 10.1249/MSS.0000000000001711.
20. Ubago-Guisado E, Gómez-Cabello A, Sánchez-Sánchez J, García-Unanue J, Gallardo L. Influence of different sports on bone mass in growing girls. J Sports Sci. 2015;33(16):1710-1718. doi: 10.1080/02640414.2015.1004639.
21. Vlachopoulos D, Barker AR, Williams CA, et al. The impact of sport participation on bone mass and geometry in male adolescents. Med Sci Sports Exerc. 2017;49(2):317-326. doi: 10.1249/MSS.0000000000001091.
22. Gomez-Bruton A, Montero-Marin J, González-Agüero A, et al. The effect of swimming during childhood and adolescence on bone mineral density: a systematic review and meta-analysis. Sports Med. 2016;46(3):365-379. doi: 10.1007/s40279-015-0427-3.
23. PP R. Human experimentation. Code of ethics of the world medical association. Declaration of Helsinki. Br Med J. 1964;2(5402):177-177. doi: 10.1136/bmj.2.5402.177.
24. Faul F, Erdfelder E, Lang A-G, Buchner A. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39(2):175-191. doi: 10.3758/BF03193146.
25. Magkos F, Kavouras SA, Yannakoulia M, Karipidou M, Sidossi S, Sidossis LS. The bone response to non-weight-bearing exercise is sport-, site-, and sex-specific. Clin J Sport Med. 2007;17(2):123-128. doi: 10.1097/JSM.0b013e318032129d.
26. Maurel D, Boisseau N, Benhamou C, Jaffre C. Alcohol and bone: review of dose effects and mechanisms. Osteoporos Int. 2012;23(1):1-16. doi: 10.1007/s00198-011-1787-7.
27. Miller AJ, Jones C, Liss F, Abboudi J, Kirkpatrick W, Beredjiklian P. Qualitative evaluation of digital hand x-rays is not a reliable method to assess bone mineral density. Arch Bone Jt Surg. 2017;5(1):10. doi: 10.22038/abjs.2016.7868.
28. Gomez-Bruton A, Montero-Marín J, González-Agüero A, et al. Swimming and peak bone mineral density: a systematic review and meta-analysis. J Sports Sci. 2018;36(4):365-377. doi: 10.1080/02640414.2017.1307440.
29. Risser WL, Lee E, LeBlanc A, Poindexter H, Risser J, Schneider V. Bone density in eumenorrheic female college athletes. Med Sci Sports Exerc. 1990;22(5):570-574. doi: 10.1249/00005768-199010000-00005.
30. Lee E, Long KA, Risser WL, Poindexter H, Gibbons WE, Goldzieher J. Variations in bone status of contralateral and regional sites in young athletic women. Med Sci Sports Exerc. 1995;27(10):1354-1361. PubMed PMID: 8531605.
31. Zouch M, Chaari H, Zribi A, et al. Volleyball and Basketball Enhanced Bone Mass in Prepubescent Boys. J Clin Densitom. 2016;19(3):396-403. doi:10.1016/j.jocd.2015.07.001.
32. Gray, Henry. Anatomy of the human body. Vol. 8. Lea & Febiger, 1878.
33. Peretti GM, Domenicucci M. Bone Structure and Function in the Distance Runner. Management of Track and Field Injures. 2022:55-60.doi: 10.1007/978-3-030-60216-1_6.
34. Mudd LM, Fornetti W, Pivarnik JM. Bone mineral density in collegiate female athletes: comparisons among sports. JJ Athl Train. 2007;42(3):403.
35. Scofield KL, Hecht S. Bone health in endurance athletes: runners, cyclists, and swimmers. Curr Sports Med Rep. 2012;11(6):328-334. doi: 10.1249/JSR.0b013e3182779193.
36. Stojanović E, Stojiljković N, Scanlan AT, Dalbo VJ, Berkelmans DM, Milanović Z. The activity demands and physiological responses encountered during basketball match-play: a systematic review. Sports Med. 2018;48(1):111-135. doi: 10.1007/s40279-017-0794-z.
37. Mroczek D, Januszkiewicz A, KawczyNski AS, Borysiuk Z, Chmura J. Analysis of male volleyball players' motor activities during a top-level match. J Strength Cond Res. 2014;28(8):2297-2305. doi: 10.1519/JSC.0000000000000425.
38. Hind K, Truscott JG, Evans JA. Low lumbar spine bone mineral density in both male and female endurance runners. Bone. 2006;39(4):880-885. doi:10.1016/j.bone.2006.03.012.