

## A review of the effect of swim training and nutrition on bone mineral density in female athletes

Namju Lee<sup>1</sup> and Jongkyu Kim<sup>2\*</sup>

<sup>1</sup>Department of Sports Medicine, School of Arts & Sports Science, Jungwon University, Chungbuk, Republic of Korea

<sup>2</sup>Aribio Sports Science Institute, Yongin University, Gyeonggi-do, Republic of Korea

(History: Received: 2015/10/06, Revised: 2015/11/12, Accepted: 2015/11/30, Published: 2015/12/31)

Namju Lee and Jongkyu Kim. A review of the effect of swim training and nutrition on bone mineral density in female athletes. *JENB.*, Vol. 19, No. 4, pp.273-279, 2015 [Purpose] The present paper reviews the physiological adaptation to swim training and dietary supplementation relating to bone mineral density (BMD) in female swimmers. Swim training still seems to have conflicting effects on bone health maintenance in athletes. [Methods] This review article focuses on swim training combined with dietary supplementation with respect to BMD in female athletes. [Results] Upon review of previous studies, it became obvious that the majority of studies did not collect physical activity data on the swimmers outside of their swimming activities. These activities may have some influence on the BMD of swimmers and therefore, future studies need to examine additional physical activity history data as well as swim training. This additional information may help to explain why swimmers' BMD tends to be lower than the BMD of control individuals in many studies. Moreover, dietary supplementation such as calcium, magnesium, and vitamin D also affect bone health in swimmers, and it is extremely important to evaluate BMD in the context of dietary supplementation. [Conclusion] A review of the literature suggests that exercise intervention studies, including longitudinal and randomized control trials, need to attempt to introduce various exercise programs to female swimmers in order to determine the optimal exercise prescription for bone health. [Key words] Swim training, nutrition, bone mineral density

### INTRODUCTION

It is known that swimming is a non-weight-bearing activity that can increase aerobic capacity and lean body mass, however, it has no positive effects on bone mineral density (BMD) [1-5]. The loss of bone volume and quality due to a lack of mechanical stimuli can be explained by Wolff's Law [6]. Bone loss may induce osteoporosis later in life, a skeletal disease characterized by low bone mass and microarchitectural deterioration of bone tissue, leading to increased susceptibility to fractures. Osteoporosis has become a poignant health problem, particularly for women [7,8], and it has long been known that female athletes, especially swimmers, have menstrual irregularity [9-11]. Females are more vulnerable to bone loss as a result of having smaller skeletons compared with males, and the estrogen patterns that accompany menarche and menopause. Hence, low BMD associated with menstrual irregularity in female athletes may

cause severe health problems later in life.

Previous cross-sectional studies have compared the BMD of competitive swimmers to other competitive athletes, showing that the BMD of collegiate swimmers is significantly lower than that of their counterparts who participate in impact exercise and equal to or lower than that of non-athletic controls [12,13]. The results of these studies indicate that swimming is not beneficial for the promotion, maintenance, or increase of BMD. Conversely, several studies have addressed that there is no significant difference between swimmers and controls with respect to BMD [14-16].

As shown in a previous study [17], bone-exercise-nutrition interaction exists, and therefore, studies that evaluate the effect of dietary supplementation in swimmers are needed in order to find out the possible interaction between training and bone health. Nutritional aspects such as calcium, magnesium, and vitamin D may also affect bone health in swimmers.

To date, swim training still seems to have conflicting effects

\* Corresponding author: Jongkyu Kim, Tel. 82-31-8020-3139, Email. [swrhrnak@gmail.com](mailto:swrhrnak@gmail.com)

©2015 The Korean Society for Exercise Nutrition

**Table 1.** Summary of the comparison factors in this review

Comparison factors		
Group	Non-impact sports	Swimming
		Impact sports
BMD (Bone Mineral Density)	Z-score of -2 or below	
Bone turnover markers	DPD (deoxypyridinoline), bone resorption markers	
	PICP (carboxyterminal propeptide), bone formation markers	
Nutritional supplements	Calcium, magnesium, iron, vitamin D	

on bone health maintenance in female athletes. Therefore, the present review focuses on swim training, dietary supplementation, and BMD in athletes from prior representative research from the 1990s to date, with a view to elucidating the effect of swim training on BMD in the athletic population. The comparison factors in this review are presented in Table 1.

#### *Definition of low bone mineral density in athletes*

The International Society of Clinical Densitometry (ISCD) [18] recommends the use of Z-scores rather than T-scores, because they compare BMD with age- and sex-matched controls. ISCD defines a Z-score of -2 or below as low BMD under the expected age, and recommends that a diagnosis of osteoporosis be made if additional risk factors for poor bone health are identified. The American College of Sports Medicine defines the term 'low BMD' as a history of nutritional deficiencies, hypoestrogenism, stress fractures, and/or other secondary clinical risk factors for fracture, together with a Z-score between -1.0 and -2.0 due to the fact that athletes tend to have 10-15% higher BMD than the non-athletic population [19]. Although low BMD has been defined as a Z-score of -2 or below, there is no report of the characteristics of normal distribution, and therefore, the exact range of low BMD cannot be obtained. Moreover, a Z-score between -1.0 and -2.0 can be applied to members of the entire population including well-trained athletes and untrained individuals. Hence, BMD measurement in the athletic population needs to consider characteristics of the sport type and bone-loaded regions.

#### *Effect of exercise on bone*

According to Wolff's Law, in the healthy population, bone usually responds to stress by increasing its mass and BMD [6]. Bone mass can be increased by physical activities

requiring high force and/or generating high impact on bone. In previous studies, several exercise training programs have been used to improve BMD [8, 20]. In general, swimming is considered to be an unloaded exercise that has no impact on BMD, whereas exercises that include walking, jumping, running, and stopping such as basketball, running, and gymnastics are considered to be high impact sports that have a positive effect on BMD [21]. However, BMD can be also be directly affected by weight bearing and indirectly affected by repeated muscle contraction. Therefore, recent studies have focused on the relationship between BMD and the characteristics of muscle fibers based on genetic factors in animals and humans [22]. Although swim training may not actually cause positive phenotypic effects on BMD, regular and long-term exercise is repeatedly performed and thus may appear to exert positive changes in BMD. To support this suggestion, the joint effect of phenotypic activation, considering age and physiological characteristics and major and minor trace minerals affecting bone metabolism, should be conducted in order to elucidate an exact mechanism for BMD change.

#### *Negative effects of swim training on bone mineral density*

In the 1990's, studies examined and compared BMD in swimmers and athletes who participated in impact sports, concluding that swimming does not promote high BMD, based on their attempts to mechanically explain their results. Prior cross-sectional studies have demonstrated higher BMD among athletes who engage in weight-bearing and impact sports when compared with their non-athlete counterparts [23-26], as well as with their non-weight-bearing athlete counterparts [27,28].

Risser *et al.*, [29] examined the BMD among eumenorrheic female college athletes. The goal of the study was to clarify the relationship between athletic training and bone density in young eumenorrheic athletes. Swimmers had a significantly lower mean density in the lumbar spine compared with all other groups. The major conclusion of the paper is that the data support the concept that athletes in sports involving impact have a higher BMD than non-athletes and swimmers.

Taaffe *et al.*, [20] examined the role of skeletal loading patterns on BMD in eumenorrheic athletes who chronically trained using various forms of skeletal loading; the intensive impact of gymnastics, the non-weight-bearing of swimming, and the usual activity among controls. They examined 39 athletes who competed in their respective sports at the NCAA Division 1 level and 19 non-athletes who exercised three hours or less a week. The study found no difference in BMD

among the groups in either the lumbar spine or the whole body. The gymnasts and controls had greater BMD at the greater trochanter and femoral neck than the swimmers. The study concluded that high-impact weight-bearing activity is beneficial for bone accumulation, and the authors proposed that high ground reaction forces and extreme muscle contraction on bone may contribute to the higher BMD in gymnasts.

Fehling *et al.*, [15] compared the BMD of collegiate female athletes who competed in impact-loading sports (volleyball and gymnastics) and swimming. They used DXA scans to measure the total and regional BMD. Impact-loading players had greater BMD than swimmers and controls, however, there was no significant difference in BMD between swimmers and controls, at any site. This study also concluded that the prevalence of menstrual dysfunction in some participants does not appear to negatively influence BMD.

In the 2000's, Creighton *et al.*, [8] examined BMD and markers of bone turnover in female athletes with different levels of impact in their sports. They determined the effect of regular training in three different types of competitive sport on BMD, bone formation, and bone resorption in young women. 50 women participated in the study and were separated into three groups based on the degree of impact, which was determined by ground reaction forces associated with their sport. The high impact group was found to have significantly higher BMD at the femoral neck, Ward's triangle, trochanter, and a higher total BMD than the medium impact, non-impact (swimmers), and control groups. Markers of bone formation were significantly lower in the swimming group compared with the high and medium impact groups. Swimmers had high bone resorption and low bone formation markers compared with the high, medium, and control groups. The study concluded that female athletes involved in high impact sports have the greatest BMD at weight-bearing sites as well as the highest markers for bone formation.

Duncan and colleagues [30] investigated the influence of different exercise types on BMD in elite female athletes including cyclists, runners, swimmers, triathletes, and controls (15 per group). Total and areal BMD using DXA scans were conducted and it was found that running, a weight-bearing exercise, was associated with higher BMD than swimming or cycling, which is in accordance with previous studies.

In 2007, Mudd and colleagues [12] found that bone mass and sport type were important determinants of bone health in female athletes when comparing impact sports and swimming. This cross-sectional study recruited 99 collegiate female athletes in gymnastics, softball, cross country, field hockey, soccer, crew, and swimming/diving. Runners had

higher overall BMD values than other sports athletes, and swimmers and divers had a significantly lower leg BMD ( $1.117 \pm 0.086 \text{ g/cm}^2$ ) than every other sports athlete. This study concluded that greater differences among sports were seen when comparing lumbar, pelvis, and leg BMDs, and recommended that a longitudinal study would need to be conducted in order to investigate bone changes in response to training over a longer period of time in female athletes.

Maimoun and colleagues [31] investigated the BMD of gymnasts (impact activity), swimmers (non-impact activity), and controls using DXA for total and regional measurement. At baseline and the 12-month follow-up, gymnasts showed a significantly higher BMD than swimmers and controls. Moreover, the total BMD of swimmers ( $0.960 \pm 0.013 \text{ g/cm}^2$ ) was lower than that of the controls ( $0.995 \pm 0.013 \text{ g/cm}^2$ ) at baseline and the 12-month follow-up ( $0.991 \pm 0.014 \text{ g/cm}^2$  and  $1.009 \pm 0.013 \text{ g/cm}^2$ , respectively). In accordance with previous findings, this study demonstrated that the osteogenic effect of impact activity was greater than non-impact activity.

Summarizing previous studies, it has been shown that the loading-induced BMD of impact sports athletes seems to be higher compared with swimmers and/or the non-athletic population. Thus, it appears that different bone-loading history and type may highly affect skeletal adaptation in athletes. Future studies should consider this point in order to elucidate a better and clearer mechanism of the effect of swim training on BMD.

### *Positive effects of swim training on bone mineral density*

Several previous studies on BMD and other markers of bone strength have shown an advantage for swimmers compared with inactive controls and/or other sports athletes. Some researchers insist that swim training increases muscle contraction and strain on the skeleton, leading to increased mechanical loading, which would have a positive effect on BMD despite the fact that swimming generally represents a non-weight-bearing sport.

Matsumoto *et al.*, [32] examined biomarkers of bone metabolism and BMD in 103 male and female athletes. The subjects were Japanese collegiate athletes who specialized in long distance running, judo, and swimming at the national level, however, no controls were used in the study. Whole body BMD was measured using DXA, and urine samples were collected for pyridinoline (PYR) and deoxypyridinoline (DPD, bone resorption markers) using high pressure liquid chromatography (HPLC). Blood was collected for bone alkaline phosphatase (BALP) and carboxyterminal propeptide of type one collagen (PICP, bone formation markers)

measurement. All data were collected in one day. Researchers found that the total body BMD was significantly higher in judo athletes compared with runners and swimmers. Male runners had a significantly lower BALP level than male judoists, and found in BALP among the female athletes. The DPD level of male and female runners and swimmers was significantly lower than that of male and female judoists. However, the PYD level of female swimmers was not significantly different from that of runners or judoists. The conclusion by the researchers in this study was that differences in total body BMD are in part due to the demands of the specific sport, and that they are reflected in the levels of bone metabolic markers. This was the first study of its kind to examine biomarkers of bone metabolism among various types of athletes, although its results are limited and there were no control subjects. Biomarkers are best if assessed over time to determine change in bone metabolism with a given stimulus, and BMD is best when examining clinically relevant sites such as the hip and spine. Similar to this study, summarizing previous studies shows that swimmers seem to have higher levels of bone turnover biomarkers [33, 34], although they do not have a higher BMD compared with other sports athletes and/or controls.

Greenway *et al.*, [16] examined the negative effect of long-term swim training participation in 43 swimmers compared with 44 controls. Swimmers had a swimming career of over 5 years, and DXA was used to determine the total and regional BMD. In addition, they checked other activity history other than swim training. There were no differences in bone mass or BMD between the two groups, at any site. The total body Z-score of swimmers was 1.24 and of the controls was 1.18. This study concluded that long-term swim training participation did not compromise regional BMD, and swim training coupled with weight-bearing activities may induce positive effects on BMD. It appears that longitudinal swim study investigating other physical activity history is needed to verify the exact effect of swim training on BMD.

In 2014, Stanforth and colleagues compared the BMD in female athletes of various sports (basketball, soccer, swimming, volleyball) aged 18-23. They reported that female swimmers in this study had an increased BMD from baseline to year 3 post-season, although the increased amount was still smaller than that of impact sports athletes. They concluded that differences in BMD between impact and non-impact sports are large, however, this study provides evidence that swim training may increase BMD in female swimmers.

Akgül and colleagues [14] examined the effect of swim training on BMD in 79 swimmers. All swimmers had engaged in at least 2 years swim training, and DXA was used to

measure the total and regional BMD. The BMD of 68 swimmers (86%) was normal and a total of 9 swimmers (11.4%) had low BMD. This study implies that swim training may positively affect BMD, although it did not induce increased BMD in female swimmers.

Summarizing previous studies, it has been shown that swimming may be preferable for maintaining bone health, although swimming has not been shown to result in an improvement in BMD like impact sports. In addition to swim training, extra strength training may also positively affect BMD. Therefore, swim training combined with other types of training would be beneficial on the bone health of swimmers, in order to ensure a better health condition.

### *The effect of dietary supplementation on bone mineral density*

It has been stressed that reliable reports concerning the dietary habits of athletes, especially elite swimmers, are needed [35]. Several studies have shown significantly higher calcium intake in swimmers than in controls [36-38]. Other nutritional aspects such as magnesium, iron, and vitamin D may also affect the maintenance of bone health in swimmers. A healthy and well-balanced diet, including the proper amount of calcium, vitamin D, magnesium, and iron, may provide sufficient nutrients.

In 2009, Hoogenboom *et al.*, [36] determined the nutritional knowledge and eating behaviors of female collegiate swimmers. They proposed that swimming, due to the importance of a lean body weight, is associated with nutritional deficiency, and that this would lead to the development of the female athletic triad; osteoporosis, menstrual dysfunction, and eating disorders. To determine nutritional intake, they used a 24-hour recall food survey, with 85 collegiate female swimmers participating in the study. They reported a mean daily calcium intake of 1578.88 mg in all participants, which was a higher level compared with the recommended dietary allowance (RDA) of calcium (1200 mg/day). Długolecka and colleagues [37] investigated BMD using DXA in young female swimmers ( $n = 41$ , aged 11-14 years), considering nutritional aspects using a 3-day food intake recall survey. They reported that swimmers had a higher intake of calcium ( $602 \pm 229$  mg vs.  $454 \pm 236$  mg) and phosphorus ( $1390 \pm 420$  mg vs.  $1027 \pm 292$  mg) compared with non-athletic controls, although both groups had a deficiency in average calcium intake. However, they found that the mean value of BMD in both groups did not differ, indicating that in this study, a higher intake of calcium and phosphorus in swimmers may positively affect bone health when compared to controls who were not active

in sports. Czeckuk *et al.*, [39] investigated the dietary habits (calcium intake) of 18 former swimmers and 18 current swimmers, reporting that calcium intake in both groups was sufficient and did not exceed 3/4 of the daily normal. A higher calcium intake was found in former athletes compared with non-athletes. These previous studies reported that calcium consumption in swimmers was higher than the RDA and/or controls.

In contrast, several previous studies have shown that female swimmers have calcium intakes below the RDA and/or other sports athletes and controls. Berning *et al.*, [40] investigated the dietary food records of adolescent male and female swimmers, and reported that over 50% of elite adolescent female swimmers consumed lower calcium and iron intake compared with the RDA and other sports athletes. Similar to this study, Hawley and Williams [41] investigated 20 elite swimmers (11 females, 9 males) using a 4-day food intake survey, and found that 55% of swimmers consumed an intake of calcium below the RDA and 65% of swimmers had a lower intake of iron. Moreover, the mean iron intake of female swimmers was significantly lower than the RDA, and 82% of female swimmers consumed a low iron intake in this study. Based on previous studies [42-44], a low iron intake is common in female athletes. Greenway *et al.*, [16] examined the calcium intake for the previous 12 months through a questionnaire, and they also found that calcium intake was low in swimmers and controls. Swimmers achieved 83% of the recommended daily intake (RDI), however, when compared with the controls (achieved 66% of the RDI), swimmers consumed a higher amount of calcium. Czeckewski and colleagues [39] conducted a 3-year monitoring of BMD and nutrient intakes in adolescent female swimmers ( $n = 20$ ) and non-athletic controls ( $n = 20$ ). The calcium intake of swimmers was below the recommended values, and throughout the 3 years, the BMD of swimmers decreased, suggesting that this could have been due to insufficient calcium intake. Akgül and colleagues [14] examined the dietary information of 79 swimmers using a 3-day food diary, and also reported low calcium intake in the swimmers. Moreover, they found that swimmers with a normal BMD consumed a higher amount of calcium (median 700 mg) than the swimmers with a low BMD (median 600 mg). Furthermore, 31 (39.2%) swimmers in this study had a vitamin D deficiency. Vitamin D supplementation is also becoming more popular, especially in the athletic population, because it may reduce the incidence of stress fractures when combined with calcium, and may also have an ergogenic factor for athletes.

Summarizing previous studies, many authors have reported common dietary irregularities concerning female adolescent

and adult swimmers in relation to swim training. Therefore, to elucidate the exact mechanism and association between dietary supplementation and swim training, the close and precise monitoring of nutritional habits of swimmers should be conducted. In addition, proper dietary questionnaires should be developed for the athletic population.

## CONCLUSION

Upon the review of previous studies, it is obvious that the majority of studies did not collect physical activity data on swimmers' activities outside of their swimming activities. These extra activities may have some influence on the BMD of swimmers, and therefore, future studies need to examine additional physical activity history data in addition to swim training. This additional information may help explain why swimmers' BMD tends to be lower than the BMD of the controls in many studies. If a swimmer participated at a young age in impact-based sports, such as running or gymnastics, this may be reflected in their current BMD. A thorough knowledge of swimmers' past physical activity can help to better understand the results seen with DXA and biomarker analysis. Since bone adaptation to exercise is limited to loaded regions, exercise types should be carefully chosen. Nutritional intake of calcium, magnesium, and vitamin D for swimmers also needs to be considered when conducting training and BMD interaction studies. The compilation of results in this review suggests that further exercise intervention studies are needed in the attempt to introduce various exercise programs to female swimmers, in order to determine the optimal exercise prescription for bone health. Moreover, longitudinal studies and randomized control trials are necessary to better understand the association of swim training with BMD in female athletes.

## REFERENCES

- [1] Carbuñ AF, Fernandez TE, Bragg AF, Green JS, Crouse SF. Sport and training influence bone and body composition in women collegiate athletes. *J Strength Cond Res.* 2010;24:1710-17.
- [2] Emslander HC, Sinaki M, Muhs JM, Chao EY, Wahner HW, Bryant SC, Riggs BL, Eastell R, Bone mass and muscle strength in female college athletes (runners and swimmers). *Mayo Clinic Proceedings*, Elsevier, 1998, pp. 1151-60.
- [3] Hind K, Gannon L, Whatley E, Cooke C, Truscott J.

- Bone cross-sectional geometry in male runners, gymnasts, swimmers and non-athletic controls: a hip-structural analysis study. *Eur J Appl Physiol.* 2012;112:535-41.
- [4] 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;17:123-8.
- [5] Nikander R, Sievänen H, Uusi-Rasi K, Heinonen A, Kannus P. Loading modalities and bone structures at nonweight-bearing upper extremity and weight-bearing lower extremity: a pQCT study of adult female athletes. *Bone.* 2006;39:886-94.
- [6] Wolff J. *The law of bone transformation*, Berlin: Hirschwald.1892.
- [7] Chan GK, Duque G. Age-related bone loss: old bone, new facts. *Gerontology.* 2002;48:62-71.
- [8] Creighton DL, Morgan AL, Boardley D, Brolinson PG. Weight-bearing exercise and markers of bone turnover in female athletes. *J Appl physiol.* 2001;90:565-70.
- [9] Drinkwater BL, Nilson K, Chesnut CH III, Bremner WJ, Shainholtz S, Southworth MB. Bone mineral content of amenorrheic and eumenorrheic athletes. *N Engl J Med.* 1984;311:277-81.
- [10] Noakes T, van Gend M. Menstrual dysfunction in female athletes. *S Afr Med J.* 1988;73:350-5.
- [11] Wolman R, Harries M. Menstrual abnormalities in elite athletes. *Clin Sports Med.*1989;1:95-100.
- [12] Mudd LM, Fornetti W, PW.G.f.t.I.P.D. Conference, Diagnosis of osteoporosis in men, premenopausal women, and children, *J Clin Densitom.*2004;7:17-26. ivarnik JM. Bone mineral density in collegiate female athletes: comparisons among sports. *J Athl Train.* 2007;42:403.
- [13] Tenforde AS, Fredericson M. Influence of sports participation on bone health in the young athlete: a review of the literature. *PM&R.* 2011;3:861-7.
- [14] Akgül S, Kanbur N, Cinemre SA, Karabulut E, Derman O. The effect of swimming and type of stroke on bone metabolism in competitive adolescent swimmers. a pilot study. *Turk J Med Sci.* 2015;45:827-32.
- [15] Fehling P, Alekel L, Clasey J, Rector A, Stillman R. A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone.* 1995;17:205-210.
- [16] Greenway KG, Walkley JW, Rich PA. Does long-term swimming participation have a deleterious effect on the adult female skeleton?. *Eur J Appl Physiol.* 2012;112: 3217-25.
- [17] Vicente-Rodríguez G, Ezquerro J, Mesana MI, Fernández-Alvira JM, Rey-López JP, Casajus JA, Moreno LA. Independent and combined effect of nutrition and exercise on bone mass development. *J Bone Miner Metabol.* 2008;26:416-424.
- [18] Writing Group for the ISCD Position Development Conference. Conference, Diagnosis of osteoporosis in men, premenopausal women, and children. *J Clin Densitom.* 2004;7:17-26.
- [19] Nattiv A, Loucks A, Manore M, Sanborn C, Sundgot-Borgen, Warren JMP. American College of Sports Medicine position stand. The female athlete triad, *Med Sci Sports Exerc.* 2007;39:1867-1882.
- [20] Taaffe DR, Snow-Harter C, Connolly DA, Robinson TL, Brown MD, Marcus R. Differential effects of swimming versus weight-bearing activity on bone mineral status of eumenorrheic athletes. *J Bone and Miner Res.* 1995;10: 586-593.
- [21] Rubin CT, Lanyon L. Regulation of bone formation by applied dynamic loads. *J Bone Joint Surg.* 1984;66:397-402.
- [22] Yang N, Schindeler A, McDonald MM, Seto JT, Houweling PJ, Lek M, Hogarth M, Morse AR, Raftery JM, Balasuriya D.  $\alpha$ -Actinin-3 deficiency is associated with reduced bone mass in human and mouse. *Bone.* 2011;49:790-8.
- [23] Davee AM, Rosen CJ, Adler RA. Exercise patterns and trabecular bone density in college women. *J Bone Miner Res.* 1990;5:245-50.
- [24] Ferry B, Duclos M, Burt L, Therre P, Le Gall F, Jaffré C, Courteix D. Bone geometry and strength adaptations to physical constraints inherent in different sports: comparison between elite female soccer players and swimmers. *J Bone Miner Metab.* 2011;29:342-51.
- [25] Nichols JF, Rauh MJ, Barrack MT, Barkai HS, Bone mineral density in female high school athletes: interactions of menstrual function and type of mechanical loading. *Bone.* 2007;41:371-377.
- [26] Stewart AD, Hannan J. Total and regional bone density in male runners, cyclists, and controls. *Med Sci Sports Exerc.* 2000;32:1373-1377.
- [27] Pettersson U, Nordström P, Alfredson H, Henriksson-Larsen K, Lorentzon R. Effect of high impact activity on bone mass and size in adolescent females: a comparative study between two different types of sports. *Calcif Tissue Int.*2000;67:207-14.
- [28] Taaffe DR, Robinson TL, Snow CM, Marcus R. High-Impact Exercise Promotes Bone Gain in Well-Trained Female Athletes. *J Bone Miner Res.*1997;12: 255-60.

- [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;22:570-4.
- [30] Duncan CS, Blimkie C, Cowell CT, Burke ST, Briody JN, Howman-Giles R. Bone mineral density in adolescent female athletes: relationship to exercise type and muscle strength. *Med Sci Sports Exerc.* 2002;34:286-94.
- [31] Maïmoun L, Coste O, Mura T, Philibert P, Galtier F, Mariano-Goulart D, Paris F, Sultan C. Specific bone mass acquisition in elite female athletes. *J Clin Endocrinol Metab.* 2013;98:2844-53.
- [32] Matsumoto T, Nakagawa S, Nishida S, Hirota R. Bone density and bone metabolic markers in active collegiate athletes: findings in long-distance runners, judoists, and swimmers. *Int J Sports Med.* 1997;18:408-12.
- [33] Maimoun L, Mariano-Goulart D, Couret I, Manetta J, Peruchon E, Micallef J, Verdier R, Rossi M, Leroux J. Effects of physical activities that induce moderate external loading on bone metabolism in male athletes. *J Sports Sci.* 2004;22:875-83.
- [34] Lima F, De Falco V, Baima J, Carazzato JG, Pereira R. Effect of impact load and active load on bone metabolism and body composition of adolescent athletes. *Med Sci Sports Exerc.* 2001;33:1318-23.
- [35] Lamb DR, Murray R, Gisolfi CV. *Perspectives in exercise science and sports medicine.* Benchmark Press 1988.
- [36] Czeczuk A, Huk-Wieliczuk E, Michalska A, Bylina D, Soltan J, Dzieciol Z. The effect of menopause on bone tissue in former swimmers and in non-athletes. *Adv Clin Exp Med.* 2012;21:645-52.
- [37] Długołęcka B, Czezelewski J, Raczyńska B. Bone mineral content and bone mineral density in female swimmers during the time of peak bone mass attainment. *Biol Sport.* 2011;28:69-74.
- [38] Hoogenboom BJ, Morris J, Morris C, Schaefer K. Nutritional knowledge and eating behaviors of female, collegiate swimmers. *N Am J Sports Phy Ther.* 2009;4:139.
- [39] Czezelewski J, Długołęcka B, Czezelewska E, Raczyńska B. Intakes of selected nutrients, bone mineralisation and density of adolescent female swimmers over a three-year period. *Biol Sport.* 2013;30:17.
- [40] Berning JR, Troup JP, VanHandel P, Daniels J, Daniels N. The nutritional habits of young adolescent swimmers. *Int J Sport Nutr.* 1991;1:240-8.
- [41] Hawley J, Williams M. Dietary intakes of age-group swimmers. *Br J Sports Med.* 1991;25:154-8.
- [42] Brotherhood J. Nutrition and sports performance. *Sports Medicine.* 1984;1:350-89.
- [43] Newhouse I, Clement D. Iron status in athletes. *Sports Med.* 1988;5:337-52.
- [44] Short SH, Short WR. Four-year study of university athletes' dietary intake. *J Am Diet Assoc.* 1983;82:632-45.