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The Effect of Swimming Training on Bone Tissue in Humans

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Abstract

Introduction and purpose: The skeletal system performs many important functions in the human body. It primarily bears the heavy loads associated with movement, protects internal organs, and participates in the regulation of mineral homeostasis. Through continuous processes of bone remodeling and modeling, optimal levels of calcium and phosphorus in the

serum are achieved. The balanced removal of old bone tissue by osteoclasts and the formation of new bone by osteoblasts maintain the mechanical properties necessary for the proper functioning of the musculoskeletal system. Bone modeling has been shown to be activated in response to mechanical loading from physical activity. Conversely, the absence of significant loading (as in space travel, i.e., microgravity conditions) leads to increased bone resorption. Osteocytes, as the most numerous group of cells in the skeletal system, are mechanosensitive and are thought to respond to stimuli such as fluid flow, mechanical deformations, and hydrostatic pressure. In response, they regulate the work of osteoclasts and osteoblasts, translating into the regulation of processes occurring in the bone matrix.[1] It is suspected that the type, intensity, and nature of physical exercises can significantly influence these processes. The aim of this work is to gather information on the impact of swimming training (an example of physical exercise in conditions of partial gravity reduction) on the human skeletal system.

Materials and methods: The medical literature was searched using the PubMed and Google Scholar search engines. Literature was searched using keywords such as: bone, exercise, mechanical loading, bone mineral content and bone density, physical activity, swimmers, bone mass. The analysis of 30 articles published between 2010-2020 was used to write the paper.

Conclusions: Swimming, like all other sports disciplines, brings many health benefits. It has been known for many years that physical activity positively affects the proper condition of the skeletal system. However, in light of the research conducted, it seems that swimming does not contribute to an increase in bone density because it takes place in an environment where the loads are reduced. These loads are the main stimulators of osteoblasts and increased bone tissue mineralization. More research is necessary on larger groups of participants, as the studies conducted so far show differences in results depending on the age and sex of the participants.

Key words: bone, exercise, mechanical loading, bone mineral content and bone density, physical activity, swimmers, bone mass

Introduction: Physical exercises positively influence the overall health of the body. Their impact on all systems is analyzed, as well as how the type of chosen activities translates into health effects. As mentioned, mechanical loading of the skeletal system positively influences the activation of osteoblasts, leading to an increase in density and other parameters of bone tissue, resulting in increased strength and resistance to injuries and reduced susceptibility to age-related degenerative processes. Swimming is one of the few sport activities where partial gravity reduction occurs due to the water environment and the distribution of forces acting on the body placed in it. This leads to many positive aspects associated with less stress on the joints. This work aims to analyze how it affects bone mass building compared to non-exercising individuals and those practicing other sports disciplines.

1. Osteoporosis and Social Background

Osteoporosis is a common phenomenon in older people. It is associated with the occurrence of pathological fractures in these age groups, exposing many people to hospitalization, loss of physical fitness and independence, as well as increasing mortality and social costs. This disease is characterized by decreased density and disrupted architecture of bone tissue. The critical period for bone mass gain is adolescence. Epidemiological studies indicate that achieving a high peak bone mass during growth can reduce the risk of osteoporosis and thus osteoporotic fractures later in life. The most important factors influencing bone mass gain, apart from genetic and physiological factors and the intake of vitamin D and calcium, include physical activity. Therefore, practicing sports during the growth period may significantly prevent skeletal system pathologies in later life.[9]

2. Exercises Type Characteristics

Bone tissue is stimulated to increase its mass and change its mineral composition through impacts and mechanical loads. The modification of bone mineral content (BMC) and bone mineral density (BMD) allows adaptation to new demands. Not all sports have the same effect on these parameters, as they involve different degrees of skeletal system loading.[9] The degree of loading is related to the characteristics of the exercises and the environment in which these exercises take place. Water is a specific type of environment characterized by partial gravity reduction and, in consequence, the load applied to the body during movement. This undoubtedly has beneficial effects, such as the possibility of strengthening muscles without stressing the joints, but what impact does it have on bone tissue? Does the composition and density of bones change due to swimming training?

3. Measurement Methods

Dual-energy X-ray absorptiometry (DXA) is used to assess bone parameters and is the "gold standard" for measuring bone mass. It was used to assess BMC and BMD. Peripheral quantitative computed tomography (pQCT) provides data on cortical and trabecular bone, thus the internal architecture, geometry, and current bone strength. Another technique for assessing bone parameters in swimmers is quantitative ultrasonography (QUS). Its use in young populations is rapidly gaining support because the results are less affected by bone size, and the technique is less expensive and invasive than other radiological methods.[9]

4. Models Used for Studies

Some clinical studies have shown that regular physical exercise increases bone strength and reduces the risk of fractures.[2][3] Mice and rats are mainly used as suitable animal models for studying these relationships. Relatively recently, some species of fish, such as zebrafish, have been used. The bone structure of this species shows significant similarities to human bone, providing great opportunities for analyzing the impact of various environmental factors on the development of diseases and other skeletal pathologies.[1] Studies on the impact of exercise on bone structure in humans are primarily based on BMD measurements using DXA.[6] However, data from these studies are insufficient, so animal models are still used. In humans, bone formation occurs as a response of osteocytes to bone stress resulting from muscle force. It has been observed that many types of sports have a beneficial effect on bone quality, especially mineralization.[4][5] Areas of bones exposed to greater loads are characterized by higher osteoblast activity. Bone mineralization affects greater mechanical strength. Experimental exposure of zebrafish to increased exercise using opposing water currents showed increased new bone formation and increased mineralization.[1]

5. Active Childhood and Bone Health in Adulthood

Childhood and adolescence are critical periods when the skeleton is most sensitive to exercise. Several pieces of evidence have shown that promoting physical activity during bone development maximizes the chances of bone gain, potentially delaying the onset of osteoporosis in later life. The response of bone tissue to mechanical stimuli is conditioned by age, hormone levels, and other metabolic factors; furthermore, it depends on the age of onset, magnitude, duration, and frequency of stimuli. Since the benefits of exercise are widely

known, physical activity is considered the best non-pharmacological treatment for pathologies such as osteoporosis, obesity, diabetes, and cardiovascular diseases. Therefore, encouraging people to be active throughout their lives can offer many benefits beyond bone health.[24]

In healthy individuals, bone formation occurs mainly up to the age of 20, then bone mass remains more or less stable for about 20 years, and after the age of 40, destructive processes in bone tissue begin to dominate.

In a 2020 article, the authors analyzed the physiological mechanisms controlling bone remodeling, the impact of physical activity on bone health, and published studies on the effect of exercise on reducing bone aging. They emphasize that the risk of osteoporosis largely depends on the first two decades of life and how bone density was built during this time. Many data indicate that bone mineral gain is maintained with age, despite reduced physical activity in adulthood. In a randomized controlled trial of selected first- and fifth-grade children, Meyer et al. showed that the positive effects of a nine-month daily physical education program maintained BMC of the whole body, femoral neck, and hip for about three years, regardless of the stage of maturation.[23] Moderate physical activities supported by body weight, such as running and jumping, have a more positive impact on bone gain than activities that do not require body weight support, such as swimming. Children who engage in running, gymnastics, and dancing show a significant increase in BMD of the femoral neck compared to children who swim.[24] There is a strong correlation between muscle and bone development in children, suggesting that increasing muscle mass during growth stimulates bone gain.[25] Osteogenic sports, such as soccer, increase BMC in loaded skeletal areas, while "non-osteogenic sports," such as swimming and cycling, seem to have less impact on BMC compared to sedentary individuals. This observation suggests that adolescents engaging in non-osteogenic sports should combine exercises with weight-bearing activities to optimize bone development.[24][26][27] Faienza et al. concluded that starting regular physical activity, especially during adolescence, is key to achieving healthy bones and reducing the incidence of osteoporosis and future fracture risk.

6. Swimming Adolescents vs. Adolescents Engaged in Other Sports

A 2015 study compared bone mineral content (BMC) and density (BMD) in adolescents aged 11-18 who participated in swimming, those who participated in swimming along with other

weight-bearing sports, and a normoactive control group. Male swimmers had lower BMD and BMC in several areas compared to normoactive males. However, for swimmers who also engaged in other sports, only lumbar spine BMC was lower than that of the control group males. Swimmers showed lower BMD and BMC compared to swimmers who participated in other sports. Female swimmers had higher arm BMD and leg BMC than the female control group, whereas female swimmers who also engaged in other sports only had higher leg BMC than the female control group. Unlike the males, female swimmers exhibited higher BMD and BMC than female swimmers who participated in other sports. No differences were found in QUS values between swimmers and the control group. In summary, although more information is needed regarding females, it appears that for males, swimming is associated with lower BMC and BMD.[7]

7. A meta-analysis comparing swimmers' BMD with other athletes

A systematic review and meta-analysis from 2016 found that swimmers achieved similar bone mineral density (BMD) values to sedentary control groups and lower than those of other athletes engaged in weight-bearing sports. The differences in BMD of the femoral neck and lumbar spine between swimmers and sedentary control groups, as well as between swimmers and athletes participating in osteogenic sports, appeared to increase with age, favoring the non-swimming groups. There were no differences based on gender. The authors of the publication concluded that, despite its many health benefits, swimming is not an effective way to improve bone mineral density, and swimmers need to incorporate additional osteogenic exercises to achieve an increase in BMD.[8]

8. Swimming Has a Positive Impact on Bone Metabolism

A 2013 systematic review conducted by Alejandro Gómez-Bruton et al. summarized the knowledge on the impact of swimming on bone mass, structure, and metabolism. The study assumed that since swimming occurs in conditions of hypogravity, it might sometimes be associated with a decrease in bone mass. The review included 64 studies on the subject. Swimmers were found to have lower bone density than other athletes, comparable to those with a sedentary lifestyle. However, numerous studies showed increased bone turnover in swimmers compared to non-active individuals, which could result in a stronger structure and, consequently, more fracture-resistant bone tissue. The conclusions stated that swimming does

not appear to have an adverse effect on bone mass, but other types of physical activities should be preferred to improve it.[9]

Summary

Swimming is a sport with numerous health benefits. It positively affects many systems of the human body. However, its impact on bone tissue is not fully understood. Many studies indicate that physical exercises in a water environment positively affect muscles and joints but do not ensure an increase in bone density. Numerous publications suggest the necessity of supplementing swimming training with other forms of exercise conducted under load-bearing conditions to build substantial bone mass, and consequently, for the primary prevention of skeletal system diseases and pathologies such as osteoporosis. However, further research is still recommended to thoroughly characterize this phenomenon, as previous observations were conducted on small groups of individuals. The results of these studies showed variation based on age and gender.

DISCLOSURE

Author's contribution

Conceptualization, DR, GRS, PSR, WK; methodology, DR, BJ, JD; software, WK, RO; check, DR, MB, PSR and GRS; formal analysis, GRS, PM; investigation, PSR; resources, WK; data curation RO, MB, PS; writing - rough preparation, PSR, BJ, JD; writing - review and editing, DR, PS, PM, JD; visualization, DR; supervision, PS, BJ, MB; project administration, PSR, PM, RO; receiving funding, no specific funding.

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