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An Explorative Literature Review of The Influence of Physical Exercises on Bone Mineral Density

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Abstract
Introduction: With age, bone mineral density decreases, and as a result the risk of fracture increases. It is known that practicing physical exercises helps maintain or increase bone mineral density in both men and women. Fractures resulting from osteoporosis become increasingly common in women after age 55 years, resulting in substantial bone-associated morbidities, and increased mortality and health-care costs. Physical exercises stimulates the bone and it adapts to the applied mechanical forces, stimulating the obsteoblast and inhibiting osteoclast formation and activity. ***Purpose:*** The purpose of this study is to highlight the benefits of physical exercise on bone cells and bone mineral density, respectively. ***Methods:*** We searched Science Direct, Springer Link, Web of Science and PubMed for articles and reviews in the English language pusblished between 2000 and 2020, although older references were also used when appropriate. The following terms were used to give as broad range of studies as possible: „osteoporosis", „bone density", „bone mass", „physical exercise", „strength training", „osteoblast", „osteoclast", „bone physiology". ***Results:*** We limited the search to the following study designs: controlled clinical trials, guidelines, meta-analyses, systematic reviews and randomised controlled trials. Of all the articles found, we selected 98

scientific articles from which we selected the most conclusive information. ***Conclusion:*** In conclusion, we recommend practicing physical exercises from childhood, since numerous studies carried out in young, adults and in the elderly demonstrate the beneficial effects of physical exercise on bone cells, especially on osteoblasts.

Keywords: osteoporosis, bone mass, osteoblast, osteoclast

Physical exercises and bone density

Regarding the treatment of osteoporosis, the National Osteoporosis Foundation recommends that it starts with a non-pharmaceutical approach, including weight-bearing exercises that result in increased muscle mass and bone mineral density (Hinton, Nigh, & Thyfault, 2015).

Numerous nonpharmacological interventions can be implemented to reduce the risk of bone loss and fracture, and these prevention methods are recommended not only for osteoporosis patients, but for the entire population (AACE Osteoporosis Task Force, 2003), (North American Menopause Society, 2006).

It is anticipated that there will be approximately 89 million people aged 65 and over by 2050 (Jacobsen, Kent, Lee, & Mather, 2011). With the increase in the number of elderly people worldwide (Quirino, Modesto-Filho, Vale, Alves, Leite, & Brandao-Neto, 2012), the interest for one's own health is increasing, as it is known that with the aging, the physical decline appears, cardiorespiratory capacity decreases (Weiss, Spina, Holloszy, & Ehsani, 2006), (Kendall & Fairman, 2014), body fat and adipose tissue increases (Nassis & Geladas, 2003), (Kim, Shin, Lee, Myung, & Kim, 2012) which may lead to increased morbidity and mortality worldwide (Rossi, et al., 2011), (Quirino, Modesto-Filho, Vale, Alves, Leite, & Brandao-Neto, 2012).

The incidence of hip fractures globally is 2.7 million in persons aged 50 years or older, and half of these fractures can be attributed to osteoporosis (264.162 in men and 1.100.555 in women); What is noteworthy is that 59.3% of hip fractures in women could be prevented (Oden, McCloskey, Johansson, & Kanis, 2013).

Unwanted weight gain, decreased muscle mass and bone density, increased risk of diabetes, high blood pressure, cardiovascular, rheumatic and cancer disorders can be prevented by exercising (Colberg, et al., 2010), (Paynter et al., 2010). Exercises that require carrying or overcoming some weights are very effective in increasing bone mass and muscle strength, conditions that are increasingly encountered by women in this period (Chahal, Lee, & Luo, 2014). Eliminating sedentarism from our lives would have a positive impact on population health (Lee, Shiroma, Lobelo, Puska, Blair, & Katzmarzyk, 2012).

There are numerous studies that have addressed different preventive strategies for osteoporosis, strategies that involved either pharmacological or non-pharmacological treatment, both aimed at reducing the incidence of fractures (Ensrud, 2013).

Exercises can maintain and increase bone mineral density (Flieger, Karachalios, Khaldi, Raptou, & Lyritis, 1998), (Snow-Harter & Marcus, 1991), bone properties, (Umemura, Nagasawa, Sogo, & Honda, 2008), (Falcai, Zamarioli, Okubo, Paula, & Volpon, 2015), bone formation and reduce bone resorption (Huang, Lin, Chang, Hsieh, Liu, & Yang, 2003), (Xie, et al., 2006), (Yang, Jia , Chong, Wang, Qian, & Shang, 2009).

Gravitational attraction and muscular contraction are two major mechanical forces acting on the bone during physical exercises and human body movement, both of which have bone stimulating effects (Warden, et al., 2013).

The American College of Sports Medicine recommends both aerobic exercises such as tennis, climbing stairs, walking with intermittent running times and increasing strength training to maintain bone health. For aerobic exercises they recommend 30 - 60 minutes a day, 3 - 5 times a week (frequency), with an intensity of 40% - 60% of MHR (maximum heart rate). For strength training, they recommend 5 to 12 repetitions maximum (with a load that allows the subject to perform at least 5 repetitions, but no more than 12) (intensity), for 30 - 60 minutes per day, 2 - 3 times per week.

These recommendations may vary depending on the particularities of each subject (American College of Sports Medicine, 2010).

When exercise generates sufficient strength on the bone, the subject does not need to carry extra weights on the ankles or hands to be effective and does not need to be prolonged. Short work periods followed by rest breaks after exercise seem to be just as effective (Turner & Robling, 2003). For example, exercises that involve pushing weights performed from the sitting position, such as leg press, can be as effective or even more effective than walking or running. The exercises used should target the proximal muscle groups of the target bone and which present risk factors for fracture (Hurley & Armstrong, 2012).

The influence of physical exercise on bone cells

It is well known that bone is stimulated by mechanical loads (Yokota, Leong, & Sun, 2011), and it responds to mechanical stress and adapts to the applied mechanical forces (Kohrt WM, Bloomfield, Little, Nelson, & Yingling, 2004), (Bailey & Brooke-Wavell, 2008), (Burgers & Williams, 2013).

Osteoblasts are stimulated by mechanical forces acting on the bone, which then produce different biological effects that are beneficial for bone health (Rubin, Rubin, & Jacobs, 2006).

Mechanical stimulation of bone has the effect of inhibiting osteoclast formation and activity, (Rubin, Murphy, Zhu, Roy, Nanes, & Fan, 2003), (Saunders, Taylor, Du, Zhou, Pellegrini, & Donahue, 2006).

Once the mechanical forces are exerted on the bone, the osteocytes detect the strain and activate the activity of the osteoblasts to form new bone (Ju, Sone, Ohnaru, Choi, Choi, & Fukunaga, 2013).

Osteocytes are thought to be the ones that feel the bone under mechanical pressure and then send signals to the nearest osteoclasts and osteoblasts to respond specifically to pressure / loading exerted (Bonewald LF, 2011), (Crockett, Rogers, Coxon , Hocking, &

Helfrich, 2011). If the osteocytes do not feel the mechanical load, the activation of the osteoclasts will resorb the bone (Bravo, et al., 1996).

The osteocytes occupy the gaps and are surrounded by the bone matrix. They can initiate and control local bone remodeling by integrating mechanical signals and converting them into biological messengers (Rochefort & Benhamou, 2013).

Thus, osteocytes receive mechanical stresses on the bone and then transmit them to cells on its surface (Bonewald & Johnson, 2008).

These forces increase both mineral density and bone strength, which may be some of the main reasons why physical activity is so beneficial for bone health, and it is recommended even for the prevention of osteoporosis due to the few side effects and the positive effect on osteoblast activity. (Cheung & Lora, 2012), (Niinimaki, 2012).

Exercises with moderate intensity promote bone formation and inhibit bone resorption. Thus, physical exercises have a positive impact on bone mass (Honda, Sogo, Nagasawa, Kato, & Umemura, 2008), strength, geometry and bone properties, which prevents and slows the development of osteoporosis (Welch, Turner, Devareddy, Arjmandi, & Weaver, 2008), (Senderovich & Kosmopoulos, 2018).

Mesenchymal stem cells are multipotent cells that have the ability to proliferate and differentiate into different cells including osteoblasts, chondrocytes and adipocytes. Physical exercises induce mesenchymal stem cells to differentiate into osteoblasts. A recent study compared the effects of endurance training and the effects of a sedentary lifestyle on CSM (mesenchymal stem cells) in rats and found that exercise can increase the number of cells that differentiate into osteoblasts (from mesenchymal stem cells) and inhibit adipogenic potential of these stem cells (Hell, et al., 2012), (Maredziak, Smieszek, Chrzastek, Basinska, & Marycz, 2015).

Physical exercises lead to increased mechanical signals such as dynamic tension, compression and hydrostatic pressure. These mechanical signals stimulate the osteogenetic differentiation of mesenchymal stem cells and inhibit adipogenic differentiation, which may be one of the main reasons why exercise prevents osteoporosis (Sawakami, et al., 2006).

Exercise-induced mechanical stress contributes to bone strength development by influencing collagen alignment when new bone is formed (Huiskes, Ruimermam, Lenthe, & Janssen, 2000). Thus, bone responds to mechanical loading by stimulating bone formation in areas where loading is high (Turner C. H., 2006), (Senderovich & Kosmopoulos, 2018).

Muscle activity transmits stresses to the bone, and their dynamic tightening leads to anabolic effects by stimulating the proliferation of osteoblasts (Kaspar, Seidl, Neidlinger-Wilke, Beck, Claes, & Ignatius, 2002).

On the other hand, the absence of physical activity, prolonged immobilization in bed and weightlessness have negative effects on the bone system by inhibiting osteoblast activity and by strengthening osteoclast activity (Meyers, Zayzafoon, Douglas, & McDonald, 2005).

When a subject is immobilized, the stimulus for the acquisition of bone mineral density is insufficient, which leads to increased bone resorption. This is due to the fact that osteocytes, as receptors for gravity, do not detect gravity that behaves as a physiological exciter of the bone (Herrero & Pico, 2016).

Maintaining bone mineral density starts from childhood

Practiced when we are young, exercise can have major bone structure benefits and even major benefits against fractures (Warden, Fuchs, Castillo, Nelson, & Turner, 2007), (Burrows, 2007). Exercise can positively influence adolescent bone growth, bone density, which helps prevent osteoporosis in adulthood (Kemmler, Bebenek, Stengel, & Bauer, 2015).

Regular exercise during growth can improve muscle strength by increasing the rate of bone formation, leading to a significant reduction in the risk of fracture in adulthood (Turner & Robling, 2003). An additional 10% in bone mineral density in childhood and adulthood may delay the development of osteoporosis by about 13% and consequently reduce the risk of fracture by 50% (Johnston & Slemenda, 1994), (Hernandez, Beaupre, & Carter, 2003), (Hello, Chevalley, Rizzoli, & Ferrari, 2007).

Adaptations to mechanical demands during youth turn into a higher bone resistance throughout life (Warden, Fuchs, Castillo, Nelson, & Turner, 2007), (Warden, et al., 2014). When physical activity is performed in the early years, it contributes to specific geometrical changes that offer biomechanical advantages, which leads to increased bone strength and decreased risk of fracture at an old age (Grau, Fuentes, Hdez, & Antonio, Exercise and Bone Mass in Adults, 2009).

Increased bone mineral density during youth may provide additional protection against osteoporosis at an old age (Loyd, Petit, Lin, & Beck, 2004), (Cech, 2012) and delay the risk of osteoporotic fractures (Beck & Snow, 2003), (Ondrak & Morgan, 2007), (DeBar, et al., 2006). Conversely, poor acquisition of bone density during childhood and adolescence is associated with an increased risk for fracture (Chevalley, Bonjour, Ferrari, & Rizzoli, 2011), (Bonjour & Chevalley, 2014).

Physical activity increases bone mineral density in children and adolescents (Ondrak & Morgan, 2007), (Hind & Burrows, 2007), (Loud & Gordon, 2006), (Greene & Naughton, 2006), (Vicente-Rodriguez, 2006), (Nikander, Sievanen, Heinonen, Daly, Uusi-Rasi, & Kannus, 2010). Children reach 50% - 60% of the maximum bone mass until puberty and increase to 90% (in boys) and 95% (in girls) by the age of 20 (Ondrak & Morgan, 2007).

The bone mineral density consolidation continues throughout the adult period, but the maximum bone mineral density at the level of the femoral neck and lumbar spine is reached at the end of 20 years (Weaver, et al., 2016), (Sandstrom, McGuigan, Callreus, & Akesson, 2016).

In adolescence, bone mass grows more than ever (Loud & Gordon, 2006), (Ondrak & Morgan, 2007), (Perez-Lopez, Chedraui, & Cuadros-Lopez, 2010). Individuals who are physically active during childhood and adolescence will have an increased bone mass in adulthood. Achieving peak bone mass has a major influence on the development of osteoporosis (Matkovic, et al., 1994), (Rubin, Hawker, Peltekova, Fielding, Ridout, & Cole, 1999).

Also, it is generally accepted that the skeleton responds more quickly to physical exercises during childhood and adolescence than in the adult and the elderly (Kontulainen, Sievanen, Kannus, Pasanen, & Vuori, 2003). In addition, the benefits of exercise are maintained even after the intervention has ended, if it was initiated in childhood and adolescence and not in adulthood (Weeks & Beck, 2012).

Conclusion

Therefore, practicing physical exercises has positive effects on the bone mineral content and on the peripheral region of the bone, but on the bone mineral density the changes may not be so visible.

Although it is known that exercises that involve the transport/carrying of weights are beneficial for bone formation (Papaioannou, et al., 2010), (Bergland, Thorsen, & Karesen, 2011), (Burke, Franca, Meneses, Pereira, & Marques, 2012), (Bighea, Patru, Bumbea, & Popescu, 2011), (P. Teixeira, Silva, Imoto, Kayo, Teixeira, & Goulart, 2008), (Dominguez, Prisby, Muller-Delp, Allen, & Delp, 2010), it seems that the degree of muscle strain and stress has a greater impact on osteogenesis, regardless of whether the activity involved involves the transport of weights (Beck, and others, 2011).

Thus numerous studies in children and adolescents (Macdonald, Kontulainen, Khan, & McKay, 2006), (Macdonald HM, Kontulainen, Petit, Beck, Khan, & McKay, 2008), (MacKelvie, Petit, Khan, Beck, & McKay, 2004), (Petit, Mckay, Mackelvie, Heinonen, Khan, & Beck, 2002), (Weeks, Young, & Beck, 2008), adults (Vainionpaa A., Korpelainen, Sievanen, Vihriala, Leppauluoto, & Jamsa, 2007) and the elderly (Cheng, Sipila, Taaffe, Puolakka, & Suominen, 2002), (Karinkanta, et al., 2007), (Kannus, et al., 2003), (Uusi-Rasi, Sievanen, Pasanen, Oja, & Vuori, 2002) demonstrates the beneficial effects of physical exercise on bone health throughout life (Nikander, Sievanen, Heinonen, Daly, Uusi-Rasi, & Kannus, 2010).

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