

Changes in morphometric parameters of bone tissue due to physical exercise: a systematic review

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Abstract

Introduction: It is known that physical exercise can influence the morphometry of bone tissue. This influence depends on the intensity, frequency, duration and mode of exercise. However, these aspects are not well described in literature. Furthermore, morphometric parameters for the study of bone tissue are more suitable to investigate this effect. Given these uncertainties, we intend to investigate the effects of exercise in bone morphometry. **Materials and methods:** For this study, we performed a systematic search of articles in PUBMED, MEDLINE, OLD MEDLINE, SciELO and LILACS. We used the keywords: “morphometry”, “physical exercise” and “bone”. **Results:** Initially we found a total of 40 articles. Articles in which animals were submitted to pharmacological or surgery intervention as well as those where rats had some disease or hormonal alteration were excluded. After selection according to inclusion and exclusion criteria, only three articles remained. **Discussion:** Newhall, Kenneth, Marjoleine et al. (1991) investigated the effects of exercise in a non-systematic way, with no definitions of exercise parameters. It is suggested that various features of physical exercise, besides intensity, can influence on bone mechanical properties. The results of this research show the need to establish defined standards concerning the mode, intensity, frequency and duration of exercise. **Conclusion:** It was not possible to determine which morphometric parameters are the best to represent these changes. More studies in this area are suggested in order to comprehend the influence of physical exercise on bone tissue.

Keywords: morphometry, bone, physical exercise.

1 Introduction

It is well known that physical exercise promotes several individual health benefits. The benefits most commonly related in the literature are cardiorespiratory endurance, decrease in the risk for chronic-degenerative diseases and increase in the mineral bone density (ANTUNES, SANTOS, CASILHAS et al., 2006). The increased bone density caused by weight-bearing exercises are observed in studies with both human beings (DALSKY, STOCKE, EHSANI et al., 1988) and animals (CHEN, YEH, ALOIA et al., 1994; MENDONÇA, FREITAS, RAMALHO et al., 2007).

Changes in bone tissue due to physical exercise are related to some characteristics of this tissue. Bone is a highly vascular, living and dynamic tissue, giving it a remarkable capacity for regeneration and adapting its mechanical properties according to mechanical demand (NORDIN and FRANKEL, 2003). For the growth and strengthening of bone mass, there must be minimum mechanical stress placed on it to guarantee proper bone grown and skeletal health (HAMILL and KNUTZEN, 1999).

Both densitometry and bone biopsy can be used as a way to evaluate the effects of exercise on bone tissue, however these techniques were considered inadequate to investigate the skeletal response to physical stimulus. Therefore, it was necessary to study morphometric and histological parameters

in order to better understand the beneficial effects of physical exercise on bone tissue (OCARINO and SERAKIDES, 2006).

Although the positive influence of physical exercise on process of maintenance and gain of bone mass has been well defined, there are some questions about this issue. Information about ideal mode, intensity, frequency and duration of physical exercise due to adequate bone stimulus is insufficient (RUSCHEL, HAUPENTHAL and ROESLER, 2010).

Based on this explanation, the aim of this study is to review the available evidence in literature regarding on the effects of different type of exercises on bone morphometric parameters.

2 Material and methods

The articles that compose this systematic review were obtained from the following databases: SciELO (Scientific Eletronic Library Online), LILACS (Latin American and Caribbean Health Sciences), PUBMED (National Library of Medicine and The National Institute of Health), MEDLINE (U.S. National Library of Medicine – 1997-2010) and MEDLINE OLD (US National

Library of Medicine - 1966-1996). This research was carried out during the period from October, 2010 to November, 2010. The searching strategy involved for exploring all databases was with these search terms: “physical exercise”, “morphometry” and “bone”.

In this Review, original articles involving all rat lineages submitted to all kind of physical exercise were included. Articles in which animals were submitted to pharmacological or surgery intervention as well as those where rats had some disease or hormonal alteration were excluded. Also, articles which were not wholly available on databases were excluded. There were no temporal limits in selecting the articles.

3 Results

Concerning the cross terms previously described, a total of 40 articles, were found: 23 on PUBMED, 11 on MEDLINE, 6 on MEDLINE OLD, 0 on LILACS and 0 on SciELO. After that, according to inclusion and exclusion criteria, 8 articles were selected. From these, 5 were further excluded: 4 repeated and 1 unavailable, leaving only 4 articles.

After applying the inclusion and exclusion criteria, the 4 selected articles were summarized on a table (Table 1). In this table, the following criteria were established: author and year of publication of the article, an experimental model, its model age, type, intensity, duration and frequency of exercise to which the animals were subjected, morphometric parameter evaluated and the result of this assessment.

The results of this survey indicate an incipient interest in studying morphology of bone tissue in the world. The only country where the relation between morphometry and physical exercise, according to criteria established, is studied is in United States of America (USA). In the results table, it can be observed that only three articles investigate this issue. Moreover, the oldest one is from the 1990s (NEWHALL, KENNETH, MARJOLEINE et al., 1991).

4 Discussion

In Brazil, there are some studies on bone morphometry whose aims are to analyze various influences on bone tissue, such as implanting bone grafts (YAEDÚ, BRIGHENTTI, CESTARI et al., 2004) and process of bone repair (MENDONÇA, FREITAS, RAMALHO et al., 2007). However, according to inclusion criteria of this study, it was not found studies about the influence of physical exercise on bone morphometry without inducing pharmacological, hormonal or surgical changes. This data demonstrates the great need to develop studies in this area.

In Newhall, Kenneth, Marjoleine et al. (1991), the oldest one found in this review, only two morphometric parameters were evaluated, whereas in the most recent study more parameters were added that demonstrate greater interest in approaching this issue in further detail. A technological progress associated with increased interest in investigating new morphometric parameters (MENEZES and SFORZA, 2010) can be therefore be noticed, in order to produce further studies on the morphometry of the bone.

The results of this research show the need to establish defined standards concerning mode, intensity, frequency and duration of exercise. Newhall, Kenneth, Marjoleine et al. (1991) investigated the effects of exercise in a non-systematic

way, with no definitions of these parameters. By contrast Wheeler, Graves, Miller et al. (1995) suggest that intensity and frequency can influence highly on gaining bone mass, so he proposes a detailed study of physical exercise.

According to Cunha, Pontes-Junior, Bacurau et al. (2007), high-impact exercise can lead to a loss of bone mass. Wheeler, Graves, Miller et al. (1995) have observed in their experiments that animals submitted to this intensity of exercise had a significantly less medullary area and in the cross-sectional area of marrow and cortical bone and cortical thickness. McDonald, Hegenauer and Saltman (1986) suggest that various features of physical exercise, besides intensity, can influence bone mechanical properties. This reflects complex interactions between bone remodeling and exercise intensity, exercise duration, animal species and skeletal age. Up until now, there is no registration of an ideal duration of exercise in order to maintaining or increase bone density. Duration exercise had no influence on either of the morphometric parameters evaluated by Wheeler, Graves, Miller et al. (1995). In the other two articles (NEWHALL, KENNETH, MARJOLEINE et al., 1991; WARNER, SHEA, MILLER et al., 2006) found in this review, the parameters of exercise were not taken into account which demonstrates the lack of studies and the need for further research into the effect of exercise on bone morphometry.

In study of Wheeler, Graves, Miller et al. (1995), it was showed that effects on bone morphometry depend on intensity of physical training, according to decrease on marrow area due to high intensity exercise. However, Joo, Sone, Fukunaga et al. (2003) observed no significant difference evaluating the same morphometric parameter of animals that were submitted to moderate exercise. Then, the definition of the protocol of exercise, concerning to intensity, should be better investigated.

The experimental models used in the most articles were Sprague Dawley rats, only Joo, Sone, Fukunaga et al. (2003) studied a different lineage of rats. However, in the literature it is not defined what species of animals are more suitable for investigating the effects of physical exercise on bone tissue. Due to this fact, it would be interesting to find a more suitable experimental model for this purpose (HUANG, LIN, CHANG et al., 2003). Comparative studies using different experimental models that represent humans well should be used as a way of finding an appropriate model. These experimental models mimic the human organism as some invasive methods are hard or impossible to study in human subjects (WHEELER, GRAVES, MILLER et al., 1995).

Regarding the age of experiment models, the articles which compose this review investigate the following animal ages: 28, 40, 90 and 120 days from birth. It is known that bone tissue structure of humans varies with age. In the first two decades of life (childhood until early adulthood), there is a progressive and massive increase of bone mass. But from the second decade there is a progressive and absolute loss of bone mass (ROSSI, 2008). According to bone age, there could be different effects of physical exercise on bone mechanical properties, so it is extremely important to take age into account when studying bone tissue.

The article by Warner, Shea, Miller et al. (2006) brings an innovation when comparing this with the other articles, because it investigates effects of exercise with (running) and

Table 1. Studies that evaluated bone morphometry due to physical exercise on animals.

Author/year/ country	Sample	Sample age	Aim	Mode/intensity/ duration/frequency of exercise	Morphometric parameters	Main results
Newhall, Kenneth, Marjoleine et al. (1991); EUA	Sprague-Dawley Rats	40 days	To determine if voluntary exercise leads to changes in the geometric properties of bone	Wheel cages, 6 weeks, ad libitum.	Femoral midshaft cross-sectional area.	Femoral midshaft cross-sectional area was greater in exercised animals.
Wheeler, Graves, Miller et al. (1995); EUA	Sprague-Dawley Rats	90 days	To evaluate the effects of various intensities and durations of treadmill running on bone mass and strength	Treadmill; intensity: Low (55%VO _{2max}), Medium (65%VO _{2max}), High (75%VO _{2max}); Duration: 30, 60, 90 minutes; 10 weeks.	Total bone tissue area; marrow area; cortical bone area; mean cortical thickness of tibia.	Total bone tissue area, cortical bone area and mean cortical thickness were greater in exercised animals; High intensity < marrow area; Medium intensity < mean cortical thickness.
Joo, Sone, Fukunaga et al. (2003); Japan	Wistar rats	28 days	To clarify the changes in the distal femoral metaphysis after endurance treadmill exercise	Treadmill; Intensity: moderate; Duration: 60 minutes; 10 weeks.	Cortical bone area; Bone marrow area.	The cortical bone area was significantly higher in exercised group. There was not found significant difference in bone marrow area.
Warner, Shea, Miller et al. (2006); EUA	Sprague-Dawley Rats	120 days	To investigate the effects of exercises with (treadmill) and without weight bearing (swimming) on trabecular and cortical bone.	Treadmill or swimming; 12 weeks; 60 minutes - per day, 5 days per week; same frequency.	Cortical area, marrow area, cortical thickness, periosteal perimeter, endocortical perimeter of femur and humerus.	There was no difference in femur morphometry comparing it with humerus, either in swimming or treadmill exercise.

without weight bearing (swimming), as well as comparing them. The exercise with weight bearing can lead to bone mechanical alterations (RUEFF-BARROSO, MILAGRES, VALLE et al., 2008). Despite several studies having shown some benefits of swimming to both humans and animals they are still insufficient to prove its effects on bone morphometry.

Three quarters of the articles analyzed the effect of exercise of bone provided by aerobic exercise on treadmill. This is relevant, because, nowadays treadmill is widely used as program of physical training for people of all ages (CAMARGO FILHO, VANDERLEI, CAMARGO et al., 2005).

It can be observed on the results table that depending on the mode of exercise, the bone chosen to be studied is different. When studying the effects of swimming, the bone selected was the femur, but in studying running, the chosen bone was the tibia. According to Warner, Shea, Miller et al. (2006), both mode exercises lead to the same alteration on bone tissue regardless of the bone chosen.

5 Conclusion

Bone morphometric alterations due to physical exercise depend on various factors, such as mode, intensity, frequency and duration of physical exercise, besides bone ages. However, the current studies are insufficient to ensure what parameters are likely to influence properly. It is suggested, therefore, that more studies be done in order to fill in the gaps.

References

- ANTUNES, HKM., SANTOS, RF., CASILHAS, R., SANTOS, RVT., BUENO, OFA. and MELLO, MT. Exercício físico e função cognitiva: uma revisão. *Revista Brasileira de Medicina do Esporte*, 2006, vol. 12, n. 2, p. 108-114.
- CAMARGO FILHO, JCS., VANDERLEI, L., CAMARGO, RCT., OLIVEIRA, DAR., OLIVEIRA JÚNIOR, SAO., PAI, VD., BELANGEROS, WD. Análise histológica, histoquímica e morfométrica do músculo sóleo de ratos submetidos a treinamento físico em esteira rolante. *Arquivos de Ciências da Saúde*, 2005, vol. 12, n. 3, p. 196-99.
- CHEN, MM., YEH, JK., ALOIA, JF., TIERNEY, JM. and SPRINTZ, S. Effect of treadmill exercise on tibial cortical bone in aged female rats: A histomorphometry and dual energy X-ray absorptiometry study. *Bone*, 1994, vol. 15, n. 3, p. 313-19. [http://dx.doi.org/10.1016/8756-3282\(94\)90294-1](http://dx.doi.org/10.1016/8756-3282(94)90294-1)
- CUNHA, CEW., PONTES-JUNIOR, FL., BACURAU, RFP. and NAVARRO, F. Os exercícios resistidos e a osteoporose em idosos. *Revista Brasileira de Prescrição e Fisiologia do exercício*, 2007, vol. 1, n. 1, p. 18-28.
- DALSKY, GP., STOCKE, KS., EHSANI, AA., SLATOLSKY, E., LEE, WC. and BIRGE JUNIOR, SJ. Weight-Bearing Exercise Training and Lumbar Bone Mineral Content in Postmenopausal Women. *Annals of Internal Medicine*, 1988, vol. 108, n. 6, p. 824-828. PMID:3259410.
- HAMILL, J. and KNUTZEN, K. *Bases biomecânicas do movimento humano*. São Paulo: Manole, 1999. 532 p.
- HUANG, TH., LIN, SC., CHANG, FL., HSIEH, SS., LIU, SH. and YANG, RS. Effects of different exercise modes on mineralization, structure, and biomechanical properties of growing bone. *Journal of Applied Physiology*, 2003, vol. 95, p. 300-07. PMID:12611764.
- JOO, YI., SONE, T., FUKUNAGA, SG., LIM, SG. and ONODERA, S. Effects of endurance exercise on three-dimensional trabecular bone microarchitecture in young growing rats. *Bone*, 2003, vol. 33, p. 485-93. [http://dx.doi.org/10.1016/S8756-3282\(03\)00212-6](http://dx.doi.org/10.1016/S8756-3282(03)00212-6)
- MCDONALD, R., HEGENAUER, J. and SALTMAN, P. Age-Related Differences in the Bone Mineralization Pattern of Rats Following Exercise. *Gerontology*, 1986, vol. 41, p. 445-452.
- MENDONÇA, RG., FREITAS, AC., RAMALHO, LP., FARIAS, JG. and RIBEIRO, MMB. Avaliação Histológica do Processo de Reparo Ósseo Após Implantação de BMPs. *Pesquisa Brasileira Odontopediatria e Clínica Integrada*, 2007, vol. 7, n. 3, p. 291-296.
- MENEZES, M. and SFORZA, C. Morfometria tridimensional (3D) da face. *Dental Press Journal of Orthodontics*, 2010, vol. 15, n. 1, p. 13-15. <http://dx.doi.org/10.1590/S2176-94512010000100002>
- NEWHALL, KM., KENNETH, JR., MARJOLEINE, CM., CARTER, DR. and MARCUS, R. Effects of Voluntary Exercise on Bone Mineral Content in Rats. *Journal of Bone and Mineral Research*, 1991, vol. 6, n. 3, p. 289-96. PMID:2035355.
- NORDIN, M. and FRANKEL, VH. *Biomecânica básica do sistema musculoesquelético*. Rio de Janeiro: Guanabara Koogan, 2003.
- OCARINO, NM. and SERAKIDES, R. Efeito da atividade física no osso normal e na prevenção e tratamento da osteoporose. *Revista Brasileira de Medicina do Esporte*, 2006, vol. 12, n. 3, p. 164-168.
- ROSSI, E. Envelhecimento do Sistema Osteoarticular. *Einstein*, 2008, vol. 6, n. 1, p. 7-12.
- RUEFF-BARROSO, CR., MILAGRES, D., VALLE, J., CASIMIRO-LOPES, G., NOGUEIRA-NETO, JF., ZANIER, JF. and PORTO, LC. Bone healing in rats submitted to weight-bearing and non-weight-bearing exercises. *Medical Science Monitor*, 2008, vol. 14, n. 11, p. 231-236.
- RUSCHEL, C., HAUPENTHAL, A. and ROESLER, H. Atividade física e saúde óssea: princípios fundamentais da resposta a estímulos mecânicos. *Motriz*, 2010, vol. 16, n. 2, p. 477-484.
- WARNER, SE., SHEA, JE., MILLER, SC. and SHAW, JM. Adaptations in Cortical and Trabecular Bone in Response to Mechanical Loading with and without Weight Bearing. *Calcified Tissue International*, 2006, vol. 79, p. 395-403. PMID:17164974. <http://dx.doi.org/10.1007/s00223-005-0293-3>
- WHEELER, DL., GRAVES, JE., MILLER, GJ., GRIEND, REV., WRONSKI, TJ., POWDERS, SK. and PARK, HM. Effects of running on the torsional strength, morphometry, and bone mass of the rat skeleton. *Medicine and Science in Sports and Exercise*, 1995, p. 520-29. PMID:7791582.
- YAEDÚ, RFY., BRIGHENTTI, FL., CESTARI, TM. and GRANJEIRO, JM. Heterotopic osteogenesis induced by implantation of allogenic bone matrix graft into mouse muscle perimysium. A morphometric study. *Ciência Odontológica Brasileira*, 2004, vol. 7, n. 1, p. 21-30.

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