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Bone Mineral Density and High-Performance Aerobic Activity in Older Adults Experience in Brazil

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1. Introduction

Population aging has exhibited a significant increase in the last decades. For instance, in Brazil, recent projections by the IBGE 1 (Instituto Brasileiro de Geografia e Estatística/Brazilian Institute of Geography and Statistics) forecast a threefold increase of the elderly population by 2050 from the current 10.8% to 29.7% of the country's total population, corresponding to almost 65 million people. The life expectancy at birth of the overall population increased to 73 years in the last decade (1999-2009), ranging from 73.9 to 77 years among females and 66.3 to 69 years among males. Such aging of the Brazilian population will pose increasing challenges to the national public health system, SUS (Sistema Único de Saúde/Unified Health System), as older adults exhibit a larger number of chronic diseases, which contribute to loss of functionality and decline of the quality of life.

The expected and, indeed, already occurring consequences include the progressive increase of the demand for public healthcare services, higher numbers of hospital admissions, and the use of long-term care facilities [2, 3]. The growth of the elderly population may cause a significant increase of the prevalence of chronic diseases, frailty syndrome, and femoral head fractures, which are frequent occurrences in developed countries.

In a Brazilian population-based study involving more than 2,400 individuals older than 40 years, Pinheiro et al. 4 reported incidences of frailty fractures of 15.1% among females and 12.8% among males. A study conducted by the National Institute of Traumatology and Orthopedics (Instituto Nacional de Traumatologia e Ortopedia - INTO) in Rio de Janeiro reported that the incidence of osteoporosis was 36.4% among men older than 80 years 5. Cost studies indicate that the average cost of in-hospital intervention and surgery per patient is approximately BRL 24,000.00 (USD 11,700.00) 6.

As the number of hospital admissions due to bone fractures among the Brazilian population older than 40 years is higher than 250,000 per year [7], a total cost of approximately 3 billion dollars (BRL 6.5 billion) might be estimated. This estimate comprises only hospital expenses; the cost of home and outpatient care and the loss of patient and caregiver productivity must be added to this estimate together with the incalculable costs associated with loss of quality of life and health. Consequently population aging is an emerging and serious problem.

2. Frailty

Aging is associated with progressive manifestations of frailty, poorer capacity of adaptation, and less resilience, which is defined as the ability of individuals to address problems, overcome obstacles, or resist the pressure imposed by adverse conditions.

The conference on frailty in older adults sponsored by the American Geriatrics Society (AGS) and the National Institute on Aging (NIA) defined frailty as a “state of greater vulnerability to stressors due to age and declines related with the neuromuscular, metabolic and immune physiological reserve [8].

The correlation between frailty and orthopedic risks is patent among older adults.

Fried et al. [9] created a definition of the phenotype of frailty that is widely used in research protocols and was validated in the Cardiovascular Health Study (CHS), which was conducted with more than 5,000 men and women aged 65 years or older. According to this study, frailty corresponds to the presence of three or more of the following criteria (pre-frailty corresponds to the presence of less than three):

1. Weight loss ($\geq 5\%$ of the body weight in the past year)
2. Exhaustion (positive answers to questions on the effort needed for physical activity)
3. Weakness (reduced grip strength)
4. Slow walking speed (> 6 to 7 minutes to walk 15 m)
5. Low physical activity (Kcal per week: men < 383 Kcal, women < 270 Kcal)

In a study on the index of osteoporotic fractures, Ensrud et al. [10] applied a simpler index to define frailty, whereby it corresponds to the presence of at least two out of the three following criteria:

1. Loss of 5% of the body weight in the past year
2. Inability to rise from a chair five times without using the arms
3. Answering “no” to the question, “Do you feel full of energy?”

Several studies [11, 12] found that the two abovementioned indices were comparable in the prediction of the risk of fall, deficiency, fracture, hospital admission, and death.

There is a clear correlation between the criteria used in the definition of frailty and the factors related with fall risk and osteoporosis. From the syndromic perspective, a strong correlation exists indicating that frailty as such might be considered as a predisposing factor for falls, fractures, and their complications among the elderly population.

3. Falls

Falls are most likely the main health problem among the elderly population, frail people in particular. The risks of fractures and their complications increase together with osteoporosis.

A cohort study conducted in the city of São Paulo and involving more than 1,500 participants [13] found that 35% to 40% of the elderly individuals aged 60 years or older fall at least once per year, and this rate grows to 50% among individuals older than 80 years.

In the abovementioned study, the variables that independently and significantly correlated with increased probability of falls were female gender, previous history of fractures, difficulty to perform physical activity, and reported poor or very poor vision.

Upon investigating falls, another cohort study in São Paulo involving more than 2,000 older adults [14] reported that 33.5% of the studied population reported falls in the past year, whereby 20.2% of the participants reported one single episode, 5.9% reported two episodes, and 7.4% reported three or more episodes.

That same study clearly established a direct correlation between frailty and number and severity of falls.

4. Osteoporosis and aging

Osteoporosis and falls represent the main risk factors for the occurrence of fractures, which possibly are the main health problem of older adults.

4.1. Physiopathology

The skeleton performs a double function related with metabolism and body support.

A reduction of bone mass associated with deterioration of its microarchitecture predisposes an individual to fractures. The bone is a metabolically active tissue, undergoing constant remodeling through the action of the cells responsible for bone resorption (osteoclasts – derived from the monocyte lineage) and formation (osteoblasts – derived from the fibroblast lineage).

The control of bone resorption and formation is coordinated and synchronized by a system known as RANK-RANKL-OPG, which allows for a better understanding of bone physiology and paves the way for the development of novel treatments¹.

The cytokine RankL, a member of the TNF (tumor necrosis factor) superfamily, is expressed and secreted by osteoblasts. Interaction between RankL (expressed on the osteoblast surface) and Rank (expressed on the surface of the osteoclast precursors) mediates differentiation and activation of osteoclasts in the presence of M-CSF (macrophage colony-stimulating factor). Mature osteoclasts initiate the process of bone resorption. The interaction between RankL and its receptor on osteoclasts is controlled by osteoprotegerin (OPG). OPG is a soluble receptor belonging to the TNF family that inhibits the binding of RankL to Rank, thus preventing the recruitment, proliferation, and activation of osteoclasts, and this receptor also exerts inhibitory effects on the osteoclast precursor cells. The balance between OPG and RankL controls bone remodeling.

The balance of the RANK/RANKL/OPG system is regulated by cytokines and hormones.

Parathormone (PTH), glucocorticoids, and E2 prostaglandins increase the activity of RANKL and reduce the activity of OPG. However, transforming growth factor beta (TGF- β), 17 β -estradiol, interleukin 1 (IL-1), and TNF- α exhibit the opposite actions, i.e., they reduce the activity of RANKL and activate OPG. [3]

During growth and aging, the predominance of formation and resorption alternate in the development of bone. Formation is greater until the age of 25 years, stabilizes until the age of 35 years, then decreases progressively, exhibiting a greater decline starting at the age of 70 years. Resorption predominates starting at the age of 35 years and accelerates during the postmenopausal period and until the age of 70 years.

Osteoporosis can be classified as primary or secondary. In turn, primary osteoporosis is subdivided into

- Type I or postmenopausal, which is characterized by increased bone resorption.
- Type II or senile, which is characterized by decreased bone formation.

Secondary osteoporosis, resulting from other pathologies, may be triggered by

- Endocrine disorders: Hyperthyroidism, Diabetes, Hyperparathyroidism, Hypercortisolism, Hypogonadism
- Rheumatic disorders: Rheumatoid arthritis, Spondylitis
- Malabsorption syndromes, Inflammatory Bowel Disease, Coeliac Disease, Post-Gastrectomy
- Kidney Failure
- Neoplasias: Myeloma, Lymphoma
- Drugs: corticosteroids, anticonvulsants, alcohol, thyroid hormone.

Osteoporosis is universal among the elderly population, exhibits progressive incidence, and is directly correlated with age and lifestyle, including the practice of sports.

¹ RANK – is the abbreviation of receptor activator of nuclear factor kappa B; RANKL – receptor activator of nuclear factor kappa-B ligand; and OPG –osteoprotegerin.

5. Physical activity

Given the growth of the elderly population, the establishment of health promotion measures to reduce the prevalence of chronic diseases, improve functionality, and control multimorbidity is notably important. The goal in this regard is to improve the quality of life of older adults and to reduce healthcare expenses. Among such health-promoting measures, physical activity is one of the main factors associated with control of comorbidities and the reduction of the risk of morbimortality by cardiovascular diseases [15], diabetes [16], obesity [17], and osteoporosis [18]. Physical activity has also been correlated with improved cognition [19, 20, 21, 22] and reduced risk of the incidence of Alzheimer's disease [23].

Regular exercise is important for healthy aging because it has an influence on chronic diseases and functionality. Exercise seems to be a protective factor against genetic and molecular aging and is associated with longevity [24]. Exercise protects [25] the organism against oxidative stress [26] and inflammation [27], which cause damage to the deoxyribonucleic acid (DNA) and other cell structures, resulting in progressive loss of metabolic and physiological functions and greater propensities for cardiovascular, neurodegenerative, and oncological diseases.

The beneficial effects of physical exercise have been demonstrated in the prevention and control of cardiovascular and osteomuscular diseases and diabetes and in the prevention of neoplasias. [28] In recent years, research has focused on the beneficial effects of physical activity on cognitive functions and prevention of dementias [29].

Together with nutritional measures, hormone and calcium replacement, and use of bisphosphonates, programmed physical exercise has been reported as a protective factor against osteoporosis in older adults. Programmed physical exercise is an acknowledged source of countless benefits in all population sectors, including the elderly. Several authors have correlated the absence or reduction of such physical activity with a higher prevalence of osteoporosis.

Nevertheless, the prescription of physical activity involves a heterogeneous range of interventions, with each one possessing particular risks and benefits. Therefore, in addition to stimulating the practice of physical activities by their patients, healthcare professionals must carefully and thoroughly analyze the types of activity that are most appropriate for their intended purposes.

6. The rule of aerobic exercises

Aerobic exercises and, more particularly, walking and running, are the activities most often recommended by healthcare professionals and most widely practiced by the elderly population.

However, overly intense exercise (ultramarathon, running > 64 km per week) is associated with a larger number of osteoarticular lesions and immunosuppression. In addition, the ideal level of physical activity promoting cognitive benefits and modulating neuroprotectors and the inflammatory activity is still unknown.

Data in the literature regarding the benefits of long-distance running in the prevention of osteoporosis among older adults are controversial. Novotny et al. [30] assessed an Olympic and world champion long-distance runner 35 years after the end of his racing career and found that his joints were free of signs of arthrosis but that he presented with exceptionally advanced osteoporosis. Conversely, Maud et al. [31] studied a similar case of a long-distance runner older than 70 years who had more than 50 years of training and did not find any alterations in any system (including musculoskeletal). Additionally, regarding resistance exercise, the consensus seems to point to reduction of falls [32] and thus of fractures [33], although not necessarily of osteoporosis [34].

Several authors reported increases in bone density among high-performance runners, mainly in the femoral neck [35], whereas according to other authors, similarly to what appears to be the case of women [36], such runners exhibited reductions in bone mass with debatable physiopathology but with a possible association with the metabolism of PTH. Finally, a third group of investigators did not identify any significant differences in bone density among the various groups. [38, 39]

When aerobic activity is combined with resistance training, the increase in bone mass becomes more evident, at least at the experimental level. [40]

6.1. Metanalyses

As the literature data concerning the benefits of aerobic activity in the elderly are conflicting, conducting metanalysis can be a real benefit in his assessment.

Metanalyses of studies on anaerobic exercise and osteoporosis in women produced notably modest results [41]. Several meta-analyses studies published by the Cochrane Collaboration [42] report that both resistance and aerobic exercises might improve bone density among women, and even walking might increase bone density at the hip. It is worth noting that the authors of the abovementioned study stated that the quality of the articles included in the review was modest, whereby the reliability of the results is limited. Still, in this regard, Yamasaki et al. reported that walking improved bone density at the lumbar spine and hip in postmenopausal women. [43]

7. Our experience

To analyze the effects of high-performance physical activity among older Brazilian adults, a cohort of senior athletes from IOTFMUSP (Instituto de Ortopedia e Traumatologia do Hospital das Clínicas da USP/Institute of Orthopedics and Traumatology of the Clinical Hospital of USP) was established in 2001. During the last 11 years, athletes older than 60 years and a control group consisting of healthy non-athlete individuals older than 60 years have been followed periodically by the assessment of several parameters, including bone density and body composition.

To analyze those parameters, 44 male athletes older than 60 years (mean 64 years) who regularly run more than 15,000 meters were compared; this group included several marathon runners and a number of super-marathon runners. The control group included 18 non-athlete individuals older than 60 years (mean 66.72 years) who had positive self-perceptions of their health and were independent in their everyday life activities. The groups were comparable with $p=0.419$.

Data were collected by means of double-absorption densitometry and were subjected to descriptive statistical analysis and Student's t-test for paired samples; the chi-square test was used in calculating sport activity as an intervention factor in controls and study subjects in a 2 x 2 table.

Comparisons of bone density, measured at the femoral neck and lumbar spine, between athletes and controls did not reveal any statistical significance (tables 1 and 2).

As a complementary measure, comparative analysis of the bone density in a subgroup of athletes over a 6-year period was performed. Although that group maintained its physical activity, no significant differences were identified among the measurements (table 3).

Athletes –Femoral Neck Density		
	BMD	T - VALUE
Mean	0.958	-0.898
SD	0.152	1.175
Median	0.933	-1.100
Controls –Femoral Neck Density		
	BMD	T - VALUE
Mean	0.90	-1.22
SD	0.10	0.77
Median	0.88	-1.45
p=0.169		
BMD – Bone Mass Density in g/cm ² /T-Score or Young Adults compared in standard deviations		

Table 1. Density of the femoral neck in athletes and controls

Athletes –Lumbar Spine Density		
	BMD	T Score Value
Mean	1.01	-0.21
SD	0.57	1.54
Median	1.23	-0.02
Controls –Lumbar Spine Density		
	BMD	T Score Value
Mean	1.15	-0.89
SD	0.17	1.69
Median	1.12	-0.95
p=0.501		

BMD – Bone Mass Density in g/cm² /T-Score or Young Adults compared in standard deviations

Table 2. Density of the lumbar spine in athletes and controls

Athlete	Year	
	T – VALUE	T Score Value
Year	2001	2007
Mean	1.02	1.02
SD	0.20	0.20
Median	1.03	1.03
p=0.464		

T-Score or Young Adults compared in standard deviations

Table 3. Progression of bone density in athletes, 2001-2007

8. Discussion and conclusions

The first noteworthy aspect of our study is that only men were included, whereas most studies on osteoporosis, including those addressing physical activity, focus on women. This condition, resulting from the overall design of our cohort, was employed because although osteoporosis is less frequent among men, the consequences of its major complication, i.e., fractures, are more severe, resulting in higher indices of morbimortality among men compared to women [44].

In addition, several studies demonstrated that the incidence of osteoporosis among men increases quickly and progressively with age; in the studied area, osteoporosis may affect up to 40% of the male population older than 80 years [5].

Our data showed that predominantly aerobic activity, such as high-performance running, did not exhibit a statistically significant correlation with increased bone density; however, the density also did not decrease over a 6-year period. Therefore, our data agree with the findings by Kemmler [37] and Wisswell [38].

However, this finding places us at the center of the debates on aerobic exercise and osteoporosis.

The participants of this study belonged to a group of senior athletes with good athletic performance. An average running distance of 15 km and the fact that those athletes exhibited statistically significant improvement over the years denote effective training and follow-up.

As a measurement of bone mineral density (BMD), the femoral neck was preferentially used because it is location one most commonly tested. However, our data show that there is a statistically significant difference between the femoral neck and total body bone density that prevents their undifferentiated use.

In regard to the incidence of osteoporosis among older adults, analysis of the participants' bone densities in 2001 and 2007 (table 3) did not reveal any statistically significant differences.

Despite the small number of controls in this group, which may compromise its reliability, the data couldn't show us any perceptible difference between athletes and controls in respect to incidence of osteoporosis in concordance with international refereed data.

In the other hand we could not find alterations in bone density between comparisons with seven years of interval in the athletes group. This find may indicate that, if there were no gain in bone mass, on the other hand there were no losses, which might lead us to imagine a protective effect of bone loss in this group, confirming literature data.

These data lead us to conclude that regarding the prevention or treatment of osteoporosis in older adults, the practice of aerobic physical activity alone is controversial. In the best of cases, physical activity leads to reduced bone loss, although this finding is also poorly supported by evidence.

We are currently studying a subgroup of our cohort consisting of senior athletes practicing high-performance aerobic activity and simultaneously being subjected to parallel resistance training. We believe that the results obtained from this group might shed new light on this currently unclear aspect of the prevention and treatment of osteoporosis in older adults.

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