Effects of the physical activity on the bone mineral density and bone remodelation

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ABSTRACT

The purpose of this article is to make a review on different sportive modalities and the power training on the bone remodeling, and to discuss the possible relationship of the bone mineral density (BMD) to the muscular power and body composition. Several studies indicate that the high impact physical activity or physical activities demanding a high power production may have a benefic effect on the BMD due to the deformation that occurs in such tissue during the activity. Some authors have been assessing the effects of the physical training on some biochemical markers of the bone remodeling, since the variation on the concentrations of these markers might indicate a bone turnover or reabsorption state. Nevertheless, the inconsistency of the results found suggests that the analysis of the effects of the physical activity on the bone remodeling through these markers must be further investigated. There are many discrepancies as to the relationship of the BMD to the muscular power and body composition, mainly to determine what factors are most associated to the BMD. The determination of what type of physical activity is the ideal to increase the bone mass peak during the adolescence or even aiming to keep it later in the adult years is quite important in order to prevent and possibly treat the osteoporosis.

Keywords: Bone health. Physical exercise. Biochemical markers. Body composition. Muscular strength.

The bone mineral density (BMD) results from a dynamic process of the bone tissue formation and reabsorption called remodeling. The reabsorption causes deterioration on the tissue, while its formation is responsible by the reconstruction and strengthening of the deteriorated tissue[1]. This process occurs along the lifetime within a four to six months period[2].

The maintenance of the BMD is very important to prevent the osteoporosis, which is characterized by an accentuated decrease in the BMD[3], in which the bone matrix and minerals are lost due to an excessive bone reabsorption that is related to its formation[4]. This process is normally associated to the aging process and is an occurrence derived from the menopause[5] that leads to a higher incidence for fractures[6]. Although the bone loss is more intense in women[5,7], men also present a decrease caused by the advanced age[8].

Several studies indicate that the physical activity has a positive relationship to the BMD, and this is an important factor to its maintenance[5,9-14]. Some studies have reported the effects of several sportive modalities to the BMD in athletes or physically active individuals[12,15,16]. Among these studies, a few use the strength training, trying to increase the BMD in individuals submitted to that type of physical activity[7,13,14,17]. In general, the same studies have shown positive results related to the BMD[8,15,17-23]. Nevertheless, despite this possible benefic effect, quite large training volumes may cause a damage on the BMD, and it seems that such damage is closely related to the disturbance in the hormonal homeostasis of the organism[5,6,24].

An assessment method that has been long used to understand the physiological mechanism coming from the osteogenic effect of the physical activity is to measure some biochemical formation markers (i.e., osteoblastic secretion) concentrations and the bone reabsorption (i.e., by-products of the bone collagen) and its variations deriving from the training.

The possible variation in these concentrations might indicate an anabolism status or a bone catabolism[3].

Although the majority of studies emphasize the effect of the type of the physical exercise on the BMD, other factors seem to interfere in that variable as well, such as the muscular strength[25] and the body composition[6,19,26]. In this perspective, regardless the level of the physical activity, some studies have shown that BMD in physically active output athletes or even the sedentary ones seem to pursue an association to their muscular strength developed according to the type of the physical exercise or daily activity, and their body composition[6,19,25,26].

Based on the aspects approached in the above mentioned studies, the aim of this article is to make a review on the effects of different sportive modalities and the strength training on the bone health, and also to analyze its possible benefic or harmful mechanism. It also intends to make a review on the results attained with the biochemical markers for the bone metabolism, as a method to assess the bone remodeling related to the physical exercise, and the relationship of the BMD to other components related to the health, such as the muscular power and body composition.

1. ACTION OF THE EXERCISING ON THE BONE STRUCTURE AND REMODELING

The idea that larger overload physical activities derived from the body weight as well as the strength training cause osteogenic stimuli is a consensus in the specialized literature, due to an increase in the bone-located mechanical stress[1]. Nevertheless, the physiological process responsible by the response to that strength is not clearly explained.

According to Brighton *et al. apud* Menkes *et al.*[18], a possible justification for the increase in the BMD to the strength training is the bone piezoelectric effect. This is suggested by the presence of biochemical signals that seem to reflect an electric field possibly as consequence for the applied overload.

This theory is applied to any deformation or bone overload caused by a compression, tension, torsion or shear on such tissue. These mechanical actions generate differences in the bones' electrical power that actuates as an electrical field stimulating the cellular activity, and leading to the deposition of minerals at stressed spots (Lanyon, Hartman *apud* Menkes *et al.*)[18].

Nevertheless, the osteogenic effect derived from the physical activity appears to demand a high training level that is characterized by a great volume and intensity. Related to the practice of the

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sportive modalities, Creighton *et al.*[1] assert that the bone strengthening that results from the repetitive stress that occurs during long training periods cannot be sufficient to increase the BMD in non-competitive athletes. Madsen *et al.*[19] suggest that the higher BMD observed in athletes can be consequence of the higher physical activity level practiced during the adolescence, suggesting an increasing BMD as consequence of a long-term training. In relation to the strength training, Pruitt *et al.*[13] suggest that it is required that the muscular contraction responsible by the bone deformation surpass a given threshold, in order to stimulate the tissue remodeling. In fact, the BMD seems to respond to a higher training intensity both in human[3] and in animal models[27].

Related to the bone remodeling, according to Andreoli *et al.*[15], in the strength induction, the deformation that occurs in the structures involved can lead to an optimum formation level and to an inhibition in the reabsorption that occurs within the normal remodeling cycle.

On the other hand, Menkes *et al.*[18] verified that the increase in the BMD is due to the stimulation on the bone turnover, rather than to an attenuation of the reabsorption that occurs into that tissue. Andreoli *et al.*[15] complement this theory suggesting that at the cellular level, the remodeling process overload-induced is performed by the action of the osteocytes that actuate as mechanical receptors of the applied stress and to the releasing of a stimulating chemical factor for the proliferation of the osteoblasts at the stressed spot.

The higher osteoblast activity that are the responsible cells by the bone turnover[18], or the osteoclasts that are the responsible cells by the bone reabsorption[4] can be suggested by the increasing circulating or urinary concentrations of the substances secreted by those cells. Those substances have been used as biochemical markers for the bone remodeling, and its concentrations have been measured in athletes or individuals submitted to some method of physical training to assess an eventual effect on the bone remodeling[6,7,17,18].

Among the markers for the bone turnover, it is the specific bone alkaline phosphatase[13,18] that is secreted by the osteoblasts and hydrolyzes the phosphate esters that are probably involved in the calcification process[4], and the osteocalcin or the bone Gla protein, whose synthesis increases whenever there is a major calcification of the tissue. However, there is a discrepancy as to its use. Some researches, such as Creighton *et al.*[1] observed the osteocalcin as a marker for the bone turnover, while other authors have used such substance as marker of the own remodeling activity[7,13].

Among the bone reabsorption markers, it is the free deoxypyridolin (expressed due to the urinary creatinine)[7], the circulating levels of the tartrate-resistant acid phosphatase[18], the hydroxyproline (expressed due to the urinary creatinine)[13], the telopeptide of the Type I collagen cross-linking of the amino terminal (NTx)[1], or the urinary carboxy (CTx)[2], among other cross-linking of the circulating pyridinoline[3], and all these substances are by-products of the bone collagen turnover.

Those regions with major amounts of trabecular bone, as the lumbar spine, normally present a better response to the exercise, possibly due to the fact they are more metabolic active[11,13,18]. On the other hand, those regions with large amounts of cortical bone, as in the case of the femur, also present a response to the increase in the BMD to the exercise[3,17,18].

Such effect of the physical activity on the BMD generally happens specifically at the spots supporting the stress[15,28,29], although Rickli and Mcmanis[14] have observed a systemic effect of the physical activity on the BMD.

Although the physical activity may positively influence the bone remodeling, the biochemical process responsible by such effect is not quite clear, and other factors may mediate the effects of the physical training on the bone health, among them it is the nutrition, the individuals' genetics, and the hormonal homeostasis[15]. This can be suggested due to the existence of studies that did not succeeded in presenting an increase in the BMD upon the physical exercising[2,7].

2. THE HARMFUL EFFECT OF EXERCISING ON THE BONE HEALTH AND THE RELATED HORMONAL ASPECTS

The female sexual hormones (i.e. estrogen, progesterone) have influence on the bone metabolism due to the fact they stimulate the osteoblastic activity. This action is suggested by the existence of the estrogenic receptors in these cells (Vandershueren *apud* Maïmoun *et al.*)[5]. Furthermore, the estrogen inhibits some cytokine responsible by the osteoblast proliferation[4]. In a study performed by Helge and Kanstrup[10], the concentration of the progesterone was highly related to the BMD in rhythmic and artistic gymnasts ($r = 0.93$, $p < 0.01$), indicating an association of such hormone to these athletes' BMD.

Although the level of the physical activity is a positively related variable to high BMD values, according to Gremion *et al.*[24], the high output endurance training might lead to an early bone loss due to the effects of the sexual female hormones on the homeostasis, and a consequent secondary amenorrhea, whose clinical picture is characterized by a decreasing number of menstrual cycles[6]. Such effect is similar to what happens in postmenopausal women, whose low concentration of the sexual hormones implies in an accentuated bone loss and the consequent osteoporosis[5,7].

As to athlete women, one of the causes suggested to the bone loss process upon an intense endurance training is the low substrate level to the estrogen synthesis (i.e. the body fat)[4]. According to Burrows *et al.*[6], the bone loss in this case happens due to a caloric deficit, and an appropriate nutritional diet could avoid these hormonal disturbances on female athletes. On the other hand, Maïmoun *et al.*[5] suggest that such low hormonal production that causes the osteopenia is a consequence of the hypothalamic-hypophyseal-gonadal axle suppression derived from the high intensity exercising, suggesting the effect on the central and peripheral mechanisms for the hormonal inhibition.

The BMD behavior upon the low hormonal production appears to be different among some modalities presenting an uneven overload stimuli[10]. Frost *et al. apud* Helge and Kanstrup[10] have proposed a theoretical model suggesting that the lower estrogen concentration in the organism, the higher must be the mechanical stimuli to keep a normal BMD. In fact, comparing to sedentary women, amenorrheic and oligomenorrheal long-distance female runners presented low BMD[24], and this was not verified in oligomenorrheal rhythmic and artistic gymnasts who had that variable significantly higher than the non-physically active group[10]. Probably, this had occurred due to the fact that the load applied in the joints, imposed by some jumps performed by the athletes is quite big in such modality than the load imposed during the running.

Gremion *et al.*[24] suggest that the hormonal reposition therapy (HRT) or the use of contraceptives with estrogen content are necessary in athletes presenting clinical amenorrhea picture. In fact, those authors observed that the BMD of runners using contraceptives was significantly higher than in athletes who did not use them. On the other hand, the benefit originated by the use of contraceptives on the BMD is questioned by Burrows *et al.*[6], who did not find in their results any association between the use of oral contraceptives and the BMD on female runners. As to the HRT, its association to the physical activity was already proven to be effective to the maintenance[7] or increase[30,31] of the BMD in elder women. However, the HRT cost-benefit must be assessed, once its usage can also cause some damages to the health[4] that will not be discussed in the review.

Although there is a close relationship between the homeostasis of the sexual hormones and the BMD in women[6,24], this relationship in men is not quite clear. Colvard *et al. apud* Maïmoun *et al.*[5] showed that the androgen action on the bone remodeling of men is mediated by specific receptors for the hormones found into the osteoblasts.

However, Maïmoun *et al.*[5] observed a benefic effect of the physical training on the BMD of triathletes with low androgenic hormone concentrations. Ryan *et al.*[17] found no association between the circulating testosterone levels and the variation in the BMD occurred after the strength training applied in elder men. Nevertheless, according to Ryan *et al.*[17], the circulating testosterone levels not necessarily reflect the action of that hormone at cellular level. Maïmoun *et al.*[5] suggest that other factors may be determinant to the bone mass, mainly when hormonal concentrations are found within a normal physiological range.

In such sense, although there is a bone strengthening effect in the overloaded physical activities, the intense training may cause low hormonal production and its negative effects on the axial bone health mainly in women, and this fact cannot be underestimated.

3. EFFECTS ON THE BMD OF PRACTICING SOME SPORTIVE MODALITIES

The osteogenic effect caused by the practice of exercises using the body weight or a large muscular strength production as overload[19,23] have been suggested, once athletes involved in sports with such feature present higher BMD than is usually found in the population in general[1,23]. There are some indicatives that these types of sports are more energetic to the bone health than lower or no overload sports[19]. Nevertheless, upon the observation of such effect[1,10,12,15,19,23,28], some authors point out that the transversal feature of studies comparing individuals who have practiced several sportive modalities to less physical active individuals may present a limitation that influenced the results.

Chart 1 presents some results found in those studies assessing the effect on the BMD of practicing several sportive modalities. These results allow to suggest that some of these modalities have a stimulating effect on the bone tissue remodeling whenever it is chronically submitted to an intensity that exceeds the regular overload[15]. This effect seems to be related to the overload magnitude imposed during the exercise[1], and mainly at the specific spot where the overload is imposed[15]. This allows to stimulate the practice of higher overload sportive modalities caused by the body weight[1,19], or to spread the use of the muscular strength[15] as possible tools to prevent the bone loss and the consequent osteoporosis besides of other benefits that were not approached in this review.

CHART 1
Effects of the practice of some sportive modalities in the mineral bone density

Author	Sportive Modality	Sampling	Results
Madsen *et al.*[19]	Artistic gymnastic, soccer, volleyball, athletism and cross-country	18 to 26 years old female athletes or sedentary women	Higher total, lumbar, and femoral BMD and MBC on the athletes.
Sandström *et al.*[29]	Ice hockey	18 to 26 years old female athletes or sedentary women	Higher total, lumbar, and femoral BMD and MBC on the hockey players.
Morris *et al.*[33]	Rowing	15 to 25 years old female rowers or sedentary women	Higher total lumbar on the rowers.
Creighton *et al.*[1]	High gravitational overload sports (volleyball and basketball), medium (soccer and running) and none (swimming)	18 to 26 years old female athletes or sedentary women	Higher total and femoral BMD on the high overload group than others. Higher total and femoral BMD on the medium overload group than on no overload and controlling groups.
Andreoli *et al.*[15]	Judo, karate, and water polo	18 to 25 years old male athletes or sedentary men	Higher BMD in the arms on the judo players compared to others. Higher BMD in the legs on the karate players compared to the polo and the controlling group. Higher BMD in the trunk and MBC on the judo and karate groups.
Gremion *et al.*[24]	Long-distance runners	19 to 31 years old female runners with no menstrual disorders	Lower lumbar BMD in oligoamenorrheic women and runners using estrogen-contraceptives.
Helge and Kanstrup[10]	Artistic and rhythmic gymnastic	15 to 20 years old female athletes or sedentary women	Higher lumbar, radial, and femoral BMD on the rhythmic gymnasts than on the controlling group.
Maïmoun *et al.*[5]	Triathlon, cycling, and swimming	18 to 39 years old male athletes or physically active men	Higher femoral BMD on athletes than in the controlling group.

BMD: mineral bone density; MBC: mineral bone content.

4. STRENGTH TRAINING AND BMD

The strength training (ST) has been pointed out as one of the physical activities that results in osteogenesis[3,8,18,21,22,32-34]. Nevertheless, there are several points to be discussed as to what ST method would be more effective taking into account the exercises, the intensity and the period necessary in order to attain a bone response. Besides, the differences between the individuals' characteristics are factors that may lead to the inconsistency in the results as to the effectiveness of the ST towards a favorable influence on the bone status[13]. This can be verified once individuals with high BMD levels appear not to easily respond to the osteogenic stimulus to the ST[3,7]. However, the bone response to the ST appears to occur both in young and in elder individuals, and both in male and female individuals[8].

The mechanism to the increase in the BMD through the ST passes by the bone deformation magnitude caused during that activity. In fact, higher training intensities related to the peak load are generally associated to higher stimuli to the increasing BMD than lower intensities[3,13,17,18,22,35]. Besides, the use of higher training intensities implies in more immediate responses on the BMD[3].

Comparing to other sportive modalities, as for instance the running, an activity that is known by its osteogenic effect[5,24], practicing ST appears to present a higher stimulus to the increasing bone mass on anatomic spots where both types of physical activity result in mechanical stress, similar to what occurs in the femoral cervix[3,5,24]. It can be suggested that this occurs due to the existing relationship between the BMD to the level of the muscular strength[3,15,19,25,36], the major physical valence incremented through the ST, besides the large window of the strength gain mainly in non-trained individuals[37], allowing to apply an increasing overload propitiated by this type of training.

On the other hand, the overload imposed by the running is consequence of the body weight, and thus, it is constant along the time. Although it might have a higher amount of stimuli along the running, studies have showed that the stimulus magnitude is more important than its frequency[1,6,27,33].

Other aspect that can be considered to the optimum prescription of the type of ST with the purpose to stimulate the bone turnover is the type of muscular contraction used. So, starting from the existing relationship between the muscular strength and the BMD[2,3], it is reasonable to figure it out that the eccentric ST characterized by a major strength production than the concentric ST[38-40] would be able to promote a major osteogenic stimulus. In fact, in a study comparing the eccentric and concentric ST using the same relative load, the eccentric ST showed to be more effective in increasing the BMD[32].

Chart 2 shows a resume of the methodology, and the results found in some studies using other ST than the combination of ST and other types of physical activity methods, and with HRT, with the purpose to investigate the effects of these types of training on the BMD. The applicability of these results is very important, in order to determine the best stimulus to the bone turnover that can be useful to prevent fractures mainly in elder postmenopausal women who had more bias to the osteoporosis[5,20].

CHART 2
Strength training and mineral bone density

Author	Period	Method, intensity and volume	Sampling	Results
Rickli and McManis[14]	10 months	Aerobic gymnastic vs. ST (3x/week – non-informed intensity)	57 to 83 years old women	1.38% increase in the MBC on the training groups; 2.5% decrease in the variable on the controlling group.
Peterson *et al.*[35]	1 year	Aerobic gymnastic vs. ST (8 to 12 rep., 3x/week – non-informed intensity)	36 to 67 years old women	No increase, but ST group had the radium MBC higher than the gymnastic group after training.
Pruitt *et al.*[13]	9 months	Periodized ST (10 to 15 MR, 3x/week)	Mean 54 years old women	1.6% increase in the lumbar BMD; 3.6% decrease on the controlling group.
Menkes *et al.*[18]	16 weeks	ST in decreasing series (5 – 15 MR), 3x/week	50 to 70 years old men	2 and 3.8% increase in lumbar and femoral cervix BMD respectively.
Ryan *et al.*[17]	16 weeks	Identical to Menkes *et al.*, 1993	51 to 71 years old men	2.8% increase in the femoral cervix BMD.
Hawkins *et al.*[32]	18 weeks	Concentric vs. eccentric ST in the extensor and flexor of the knees	20 to 23 years old women	3.9% increase in the femoral BMD only on the eccentric ST.
Humphries *et al.*[7]	24 weeks	ST with and without HRT (1MR 50-80%) vs. walking with and without HRT	45 to 65 years old women	No increase, but a 1.3% decrease in the BMD on the walking group with no TRH.
Bemben *et al.*[2]	24 weeks	3 to 8MR ST vs. aerobic gymnastic group, 3x/week	41 to 60 years old women	No increase on none of the groups.
Kerr *et al.*[22]	2 years	3 to 8MR ST vs. aerobic gymnastic group, 3x/week	Postmenopausal women	1% increase in intertrochanteric BMD on the ST group.
Kemmler *et al.*[11]	14 months	Periodized ST between 50 and 90% 1MR, 2x/week added to jumping exercises	50 to 58 years old women	1.3% increase in the lumbar BMD on training group, and decrease in the lumbar and femoral BMD on controlling group.
Nichols *et al.*[33]	15 months	ST with 3 10MR series, 3x/week	14 to 17 years old women	Increase in the femoral cervix BMD on the training group.
Vincent and Braith[3]	24 weeks	50% 1MR ST x 15 rep. vs. 80% 1MR ST x 8 rep. (3x/week)	60 to 83 years old men and women	1.96% increase in the BMD in the femoral cervix on higher intensity group.
Cussler *et al.*[30]	1 year	Periodized ST with 70 to 80% 1MR, 3x/week	44 to 66 years old women	Increase in the femoral cervix BMD.
Jessup *et al.*[21]	32 weeks	Periodized 50 to 75% 1MR ST, 3x/week	66 to 72 years old women	1.7% increase in the femoral cervix BMD.
Villareal *et al.*[34]	9 months	Periodized ST with 65 to 85% 1MR, 2-3 series added to aerobic gymnastic, 3x/week	57 to 83 years old women	1.38% increase in the MBC on the training groups; 2.5% decrease in the variable on the controlling group.
Brentano *et al.*[20]	24 weeks	ST (35-80% 1MR) vs. circuit ST (35-60% 1MR), 3x/week	56 to 71 years old women	No increase in none of the groups.
Ryan *et al.*[17]	24 weeks	12 to 15MR ST, 3x/week	20 to 74 years old men and women	Increase in the femoral cervix, greater trochanter and Ward's triangle BMD, and total and leg MBC.

BMD: mineral bone density; MBC: mineral bone content; MR: maximal repetition; HRT: Hormonal reposition therapy; ST: Strength training; rep.: repetitions; vs.: versus; x/week: weekly sessions.

5. PHYSICAL ACTIVITY AND BIOCHEMICAL MARKERS FOR THE BONE METABOLISM

Besides the densitometry methods, some researchers have been using the analysis of some bone metabolism markers to assess the effects of the physical activity on the bone remodeling, in search for some relationship between changes found in the BMD and the variation in the blood or urinary concentrations of these markers[1,7,8,18]. This method has been used as a dynamic resource to assess the exercise vs. bone health relationship[1].

Vincent and Braith[3] showed that there is a relationship between the changes in the marker concentration of the bone metabolism and the densitometric changes observed, and indeed, there is a relationship between the training intensity and the magnitude of the increase in the markers for the bone turnover. Among other studies[1,18] those authors observed a major response from the bone turnover markers at higher training intensities.

Nevertheless, besides the daily variations of some markers[17], the discrepancy in its utilization[3,7], and the different responses these markers have to similar methodologies[17,18], the results on the variation in the biochemical markers not always follow the changes that happen in the BMD along the training period[17]. On the other hand, there is a possibility that it occurs an increase in the concentration of those markers, with no response on the BMD[13]. Pruitt *et al.*[13] suggest that the increase in the bone turnover markers concentration may be an early adaptation to the increasing BMD. However, another limitation that happens in using such method is that the response of the markers might represent a mean of the total body bone remodeling, rather than the spots that suffered the major overload during the physical activity. Due to such limitations, definitive conclusions related to the influence of the strength training or different sportive modalities in the bone remodeling assessed through such method still need further studies.

Chart 3 presents some studies using the biochemical markers for the bone metabolism in order to assess the effects of the physical activity on the BMD. However, due to the apparent limitations and discrepancies observed, further studies are needed in order to attain some conclusions on the effects of the physical exercising on the bone remodeling through this method.

CHART 3
Physical activity and biochemical markers for the bone metabolism

Author	Modality/Period	Sampling	Used markers	Results
Pruitt *et al.*[13]	Periodized ST (10 to 15 MR, 3x/week) for 9 months	Twenty-six mean 54 years old women	Formation: SAP Reabsorption: hydroxyproline Remodeling: OC	No increase observed.
Menkes *et al.*[18]	ST with decreasing series (15-5MR), 3x/week for 16 weeks	Eighteen 50 to 70 years old men	Formation: SAP and OC Reabsorption: TrACP	Increase in the OC and SAP concentrations and in the SAP/TrACP ration on the trained group.
Ryan *et al.*[17]	Identical to Menkes *et al.*, 1993	Thirty-seven 51 to 71 years old men	Formation: SAP and OC Reabsorption: TrACP	No increase observed.
Bemben *et al.*[2]	40% 1MR ST x 16 rep. vs. 80% 1MR ST x 8 rep., 3x/week, 24 weeks	41 to 60 years old women	Formation: OC Reabsorption: CTx	No increase observed.
Humphries *et al.*[7]	ST with and without HRT (50-80% 1MR) vs. with and without HRT walking, for 24 weeks	One hundred and sixteen 45 to 65 years old women	Remodeling: OC Reabsorption: deoxipiridinoline	Increase in the OC on the walking group without HRT.
Creighton *et al.*[1]	High gravit. overload sports (volleyball and basketball), medium (soccer and medium-distance running), and none (swimming)	Fifty 18 to 26 years old female athletes or sedentary women	Formation: OC Reabsorption: NTx	Higher OC and OC/NTx ratio on the high and medium overload groups than on the none overload and controlling groups.
Vincent and Braith[3]	50 1MR ST x 15 rep. Vs. 80 1MR ST x 8 rep. (3x/week) for 24 weeks	Eighty-four 60 to 83 years old men	Formation: SAP and OC Reabsorption: PYD	Increase in the OC, SAP and in the OC/PYD ratio on the training groups, higher percentages on the higher load group.

ST: Strength training; SAP: specific bone alkaline phosphatase; OC: osteocalcin; TrACP: resistant tartrate acid phosphatase; NTx: Type I collagen cross-linked telopeptide with amino terminal; CTx: Type I collagen cross-linked telopeptide with amino terminal; PYD: pyridinoline cross-linking; MR: maximal repetition; HRT: hormonal reposition therapy; ST: strength training; Rep.: repetitions; vs.: versus; x/week: weekly sessions; gravit: gravitational.

6. BMD, MUSCULAR STRENGTH, AND BODY COMPOSITION

Some of the studies previously mentioned in this review, among others, have searched to assess the association between the muscular strength and the body composition to the BMD, as regardless the type of the physical activity performed, it seems to be a relationship between the strength development and the body composition and BMD[3,15,19,25,36]. In general, these studies show positive correlations that range related to their level, and it have appeared some discrepancies as to the nature of such associations.

According to Hugues *et al.*[25], if there is a relationship between the muscular strength and the BMD, possibly the magnitude of the muscular contraction has impact at the bone spots that are anatomic related to the muscles performing the contraction. These authors suggest that the body weight may be an important factor to determine the BMD due to the compression strengths applied over the bones sustaining the body overload.

On the other hand, Madsen *et al.*[19] suggest that the body weight composition, including the lean and fat masses, might be more important than the body weight individually, suggesting that the fat, as a substrate to the conversion of the androgen to estrogen[26] may be related to the BMD both due to hormonal factors because of their importance in regulating sexual hormones in the BMD[5,24], and to mechanical factors. Related to the lean mass, it can be related to the BMD because although they are structurally independent, both respond to the same atrophy and hypertrophy stimuli[25].

Another relevant aspect, although not very clear, is that the associations between the BMD and the body composition and/or muscular strength suffer influence of factors such as gender[36], training level[29], and hormonal homeostasis[10].

Although there is a major relationship between the lean mass and the muscular strength[37,41,42], the associations between the lean mass and BMD not necessarily reflects the relationship observed between the muscular strength and BMD[10,25,29]. Hughes *et al.*[25] suggest that the strength would be an independent factor to the BMD, while Madsen *et al.*[19] suggest that this variable would be consequence of the lean mass, and this last one would be more associated to the BMD.

Despite the different points of view among some authors on which variable (strength or lean mass) is more related to the BMD[19,25], the major part of the studies mentioned in this topic have investigated and found some correlation of the BMD with the muscular strength and some variable related to the body composition (that means, lean and fat mass)[10,19,25,29], suggesting that all these variables are strongly related to the BMD, varying only the level of these associations.

It is appropriate to point out that there are studies mentioned in this review presenting very low correlation levels between the

BMD, the muscular strength, and the body composition components[19,25], and therefore, it is difficult to reach a conclusion from their results.

The differences observed in the associations investigated in the previously mentioned studies appear to exist due to different assessment methodologies. Besides, other factors such as hormonal regulation, training level, and gender seem to influence the level of these associations. Thus, maybe it is necessary to conduct further studies in order to determine on which population the body composition and the muscular strength are more associated to the BMD, and if the muscular strength is a variable that is dependant or not from the lean mass in its association to the BMD. Despite the limited conclusions, high levels of BMD are generally associated to the high lean mass or muscular strength levels, and the muscular strength may have a benefic effect on the BMD.

7. CONCLUSIONS AND IMPLICATIONS

Although factors such as genetics, hormonal homeostasis and food may be determinant to the BMD[15], the level of the physical activity seems to be an important influence on this variable. Despite the physiological mechanism is not completely clarified, the osteogenic action of the physical activity seems to be mediated through the bone piezoelectric effect (Brighton *et al.* apud Menker *et al.*)[18].

Some studies have shown that individuals who practice higher overload sportive modalities provoked by the body weight or with higher utilization level of the muscular strength have a major BMD[1,5,15,16,19]. The level of the bone adaptation through the exercise seems to be dependent from the overload[29], and seems to be specific for the spots that are submitted to a major stress[15,28].

In other studies, the effect of the physical activity on the BMD was investigated in individuals submitted to the ST, showing that such intervention is effective to increase the BMD in some of them[3,17], while in others, no discrepancy was observed[2]. These discrepancies may occur due to different training methodologies used by researchers or even to the sampling features (that is, high initial BMD)[13]. Nevertheless, although there are discussions as to which training variable would be the most important to stimulate the bone remodeling (that means, intensity, volume), high intensity ST seems to be more effective[3].

The use of the bone metabolism biochemical markers has been used by some authors as a possibly more dynamic mean to assess the effects of the physical exercise on the bone metabolism[1]. The variation found in the concentrations of these markers would possibly be precursor of the changes in the BMD[3]. In this event, the measurement of these concentrations become important in order to assess the optimum physical training methods aiming to attain an increase in the BMD, having in mind that higher concentrations of markers to the bone turnover may suggest an effective training not yet translated to the densitometry values (g/cm^2). However, due to the differences found in the results of some trials, it is necessary to conduct further studies in order to attain a more accurate assessment of the bone remodeling through biochemical markers.

Some studies have been demonstrated a strong relationship of the BMD to variables connected to the health, such as the muscular strength[10,29] and body composition, thus suggesting that regardless the physical activity performed, individuals with major muscular strength and lean mass might pursue major BMD, although the body fat is also related to the bone mass due to hormonal factor[6,16,19].

Nevertheless, even before such relationships, their level and nature are not completely clarified, as it was shown by the heterogeneity of the results found in the studies mentioned in this review[10,19,25,29].

To determine what type of physical activity is ideal to increase the bone mass peak during the adolescence or even with the purpose to keep it in the adult age is very important to prevent and possibly treat the osteoporosis, whose incidence occurs mainly in postmenopausal women[5]. Besides, the associations of the BMD to the muscular strength and body composition suggest that the prescription of a training aiming to improve these parameters may have a benefic effect on the BMD.

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