REVIEW ARTICLE

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Sport and its implications on the bone health of adolescent athletes

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ABSTRACT

Adolescence is a fundamental period to gain bone mass. In athletic adolescents, the maximum of bone mass can be achieved at this time. It occurs because of the stress on the bones resulted from physical exercises. The aim of this revision was to investigate the strenuous and premature exercise practice on the bone health on athletic adolescents. Through several research sessions with adolescent athletes of different gender and practicing different sports, it is possible to conclude that the mineral osseous density is potentialized as a result of exercise, when compared to control groups. However, there are numerous discussions as to the adequate intensity of physical exercise for teenagers because, in the case of strenuous training, the advantages to the bones health will be minimal or even lost. Although there is a great deal of controversy on this topic, independent of sports modality, the increase on intensity during practice should be consistent and reasonable with the goal. For different ages and biological levels, safe and efficacious exercises, should be emphasized, independent of the sports calendar.

Key words: Adolescence. Sport. Bone mass. Exercise. Bone mineral density.

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INTRODUCTION

A strong emphasis has been placed on the effects of sports on bone mass and possibility of preventing future osteoporosis[1], considering that strenuous physical exercise plays a crucial role in the bone mass gain process[2]. The load mechanisms from the exercises increase bone mineral density, regardless or gender and age of those who practice them[3].

Bone tissue dynamically responds to the imposed functional demand, causing changes in mass and strength. These changes are a result of gravity and the intense action of bone-related muscles[4]. The adaptative bone response will thus depend on the magnitude of the load and the frequency it is applied, as regular repetitions trigger osteogenic effects[2,5].

Bone mass accounts for about 80% variation in bone strength, but other factors such as bone geometry, the internal architecture, and mechanical properties also affect the strength of a given bone[1].

The continuous stress from physical exercise leads to morphological adjustments, such as increase of cortical thickness, and more bone content in the muscle-tendon insertion[4]. For other investigators, the mechanisms by which the skeleton responds to physical training are not yet fully understood[1].

Even though there are some controversies in the literature on the adaptation mechanisms of bone tissue exposed to external loads, the impact of strenuous physical exercise on bone mass is relevant during adolescence, when bone mass peak is yet to be reached[1,6,7]. The increase of bone mineral density over puberty is basically due to bone enlargement from the growth process, and further increase if cortical thickness[1].

Investigations have suggested that bone mass enlargement during growth process and immediately after it may represent an important strategy for osteoporosis prevention[1,5]. These authors report that a 3 to 5% increment of bone mineral density causes a 20 a 30% decrease in the risk of fractures. There are evidences that the peak growth period is the most effective time to potentialize bone mass gains, compared to the late adolescence period[8].

Over the past 10 years, a considerable number of professional athletes, particularly of tennis, Olympic gymnastics, swimming, soccer and other sports, have excelled at a very young age, around 15 to 17 years of age[4,9].

Because of the good results achieved by these athletes, and the interest in sports, a high proportion of young people go for sports initiation programs at clubs[4]. Starting at an early age is beneficial, due to the complexity of the technical moves and motor skills required for the practice of competition sports[4]. The sensitive period to develop such skills is between 10 and 12 years of age for females, and 10 to 13 years of age for males[10], depending on their maturity level.

The purpose of this study is to assess the effects and possible compromises caused by practice of strenuous physical activity at an early age on the bone health of adolescent athletes, from a review of the literature.

ADOLESCENCE AND SPORTS

Adolescence is a period of time when deep bio-psychosocial changes occur. According to the World Health Organization, adolescence ranges between 10 and 19 years of age[11].

The "bio" component of adolescence is known as puberty, and includes among other changes typical of that age, the development of secondary sexual traits, a rapid gain in height and weight, and changes in body composition.

The maturation of puberty is the sequence of puberty events, considered from when they appear, and the duration of each one of them. Thus, puberty is characterized by a series of predictable stages, and is presented through a series of changes of secondary sexual features[12].

The growth impulse seen in adolescence is the earliest sign of sexual maturity, and appears first in females[10]. The first event in females is typically the appearance of nipples, followed by the development of pubic hair. In male adolescents, the first event is the enlargement of testicles, followed by the development of pubic hair and, finally, penis development, first in length, then in width[12].

Female adolescents present their growth velocity peak (PHV) about two years in average before male adolescents.

The period of maximum growth reflects gains in height, from appendicular and truncal gains. The limbs grow before the trunk, and end appendicular areas grow before proximal areas. In adolescents, puberty is seen first in extremities, hands and foot, before other body changes become noticeable. After such changes, the trunk will grow.

In addition to the speed these changes occur, genetic and environmental factors play a marked role in the development of adolescents. As a result, there are variations among individuals and populations as for the beginning, duration and magnitude of puberty events.

Chronological age is not considered a suitable temporal marker, as not always it is sensitive to individual changes from the maturation process. In a same age group, adolescents of the same gender may present a marked biological variability, particularly seen in the development of secondary sexual features, which, on their turn, reflect important differences in the growth, development and physical fitness of these youths.

In relation to sports, adolescence is particularly important not only for the prescription of physical exercises to this age group, but for the whole bio-psycho-social setting of this period in life.

The importance given to body image and the appreciation by society of lean individuals may lead to a restraining eating pattern, and improper intake of nutrients and energetic food. The relentless search for beauty standards and the idealized self-image, reinforced by the media, may trigger eating disorders[6,13], which result in serious anorexia and bulimia cases, assailing particularly adolescents and young adults. Nowark (1998)[14], in an investigation with 791 Australian adolescents of both genders, aged 12 to 15, has confirmed, using a questionnaire inquiring about body image, eating habits and body weight, that most subjects were unhappy with their body image.

This unhappiness with one's own looks may lead and induce adolescents to seek high intensity physical activities and/or sports, that require a high volume of training, not only for competitive purposes, but also to reach, many a time at any cost, the idealized body.

PHYSICAL TRAINING AND ITS POSITIVE EFFECTS ON THE BONE MASS OF ADOLESCENTS

A prolonged period of rest on bed may cause important bone mineral density reduction, with an average bone loss of 4% a month. However, repeated loads of proper intensity and tension lead to bone enlargement[5]. Khan *et al.* (2001)[15], assessing data from investigations with athlete children and adolescents, showed that physical exercise is positively associated to a better bone mineral density.

Confirming this report, Mackelvie *et al.* (2002)[16], based on a literature review from 1966 until 2002, noted that during adolescence it is possible to identify a critically positive period for bone response to physical exercise.

For Nordström *et al.* (1995)[8], there is a strong association between bone mass and strength of adjacent muscles. Thus, an increment of muscle mass is reflected on a bone mass increase, i.e, the muscles, once they are excited, will trigger an osteoblastic enhancement of the bones close to their site. This fact has been seen in tennis players, who show a marked increase in bone thickness, of about 6 to 9% on the site of muscles and tendons in the radius, as consequence of forearm and arm muscle enhancement, from striking the shots[4]. This fact suggests that bone mineral density is influenced, particularly in this scenario, by repeated physical activity, and not due to other factors, such as the individual's genetics or eating habits.

The number of adolescents involved in the practice of sports markedly increased over the past few years[17,18], both in Olympic competitions and in competitive recreational sports for fun[9].

As for the type of sports and bone mineral density enhancement, cross-sectional studies with groups of athletes show that strength training enhances bone mineral density compared to aerobic endurance training[2].

There are consistent findings showing that moderate physical activities that are supported by weight, such as running and jumping, have a more positive effect on bone deposition than activities that do not require support from weight, such as swimming[19].

These findings were confirmed by Grimston *et al.* (1993)[20], who revealed that children engaged in the practice of impact sports, such as running, gymnastics and dance, for more than three times a week, present a significant increase of bone mineral density of the neck of femur when compared to children who practice swimming, and these have higher bone mineral density than children who do not practice exercises.

In a similar way, Lima *et al.* (2001)[6] observed a significant increase in bone mineral density of lumbar spine and proximal femur in 12 to 18-year boys who practiced impact sports such as basketball, gymnastics and athletics, when compared to a group of adolescents who practiced active-load sports such as water polo and swimming. And both groups presented higher bone mineral density than the control group of adolescents who did not practice any sport. One may infer that the type of physical activity influences the magnitude of bone mineral density changes in young people.

In the practice of other sports, such as skating, Slemenda and Johnston (1993)[21] observed that female skaters had their total bone mineral density increased in 5.6% when compared to non-skaters female adolescents.

The engagement of girls in sports, particularly in ballet and gymnastics, has been quite investigated. Bass *et al.* (1998)[22] measured the bone mineral density of 45 female active gymnasts, mean age of 10 years, and 36 gymnasts with mean age of 25 years, and a control group for each of these two groups. Bone mineral density of the proximal femur and lumbar spine for the active female gymnasts was of 0.7 to 1.9 standard deviations higher than controls, and bone mineral density increased accordingly to duration of training. Over a 12-month training period, female active gymnasts had higher bone mineral density than controls, of about 30 to 85% in lumbar spine and neck of femur, respectively and their bone mineral density was 0.5 to 1.5 standard deviations higher than their respective control group. The authors concluded than bone mineral density enhanced during adolescence may have a long-term effect in the life of adult gymnasts, with positive effects seen for decades after interruption of physical training.

A number of investigations have shown that the bone mass peak takes place at the stage of most intense growth, for both genders[6,7]. As to the steep bone mass increase during adolescence, studies show that Tanner's stages II and III, when associated to sports, promote a significant bone mineral density increase in most adolescents[15].

Haapasalo *et al.* (1998)[23] studied the effects of tennis training and sexual maturation using Tanner's criteria for females, and their impact on upper limbs. The results show that for Tanner's stage I, the gain in mineral density of female tennis players would occur only under intense training, and a more steep bone mineral density increase took place in Tanner's stages III and IV. The authors suggested that, at early stages of puberty, the impact on bones from the overload is not much significant, whereas in more advanced stages of sexual maturity, the hormonal pattern associated to sports leads to a higher bone mass deposition in specific sites of muscle stimulation.

Thus, assessment of sexual maturation seems to be basic for the prescription of physical fitness programs for adolescents, as the increase of gonadotropin secretion, and gonadal sexual steroids lead to sexual development, increase of body mass and height, and improvement of physical fitness of young people[10].

Nordström *et al.* (1998)[24] investigated the influence of different types of sports that support body weight, muscle strength, and puberty changes on bone mineral density of male adolescents. The first group included 12 badminton players, mean age of 17.0 ± 0.8 years, who trained 5.2 ± 1.9 h/week. The second group included 28 ice-hockey players, mean age of 16.9 ± 0.3 years, who trained 8.5 ± 2.2 h/week. The third was the control group, which included 24 adolescents with mean age of 16.8 ± 0.3 years, who trained 1.4 ± 1.4 h/week. The results showed that bone mineral density of badminton players was significantly higher than ice-hockey's, in spite of their significantly less weekly training time, showing that physical training, including jumps, has an important osteogenic effect.

Investigations reporting that interventions based on the principle that physical exercise acts on bone mass increase of children and adolescents allow the conclusion of a consistent association between these events and increased bone mineral density in adult life[22].

DOES EXHAUSTING PHYSICAL TRAINING COMPROMISE BONE HEALTH?

Skeletal reactions from different loads of a particular sport may be positive or negative[2]. During puberty, not always an intense physical training is beneficial for adolescents, particularly is regard to skeletal growth[9]. Damsgaard *et al.* (2001)[25] propose that intense strength training in adolescents seems to decrease IGF-I levels, suggesting that such training might impair growth, thus reducing final height.

Theintz *et al.* (1993)[26] showed a reduction in height and low IGF-1 level in young gymnasts that undergo intense training and low food intake in order to achieve a better body image, that influences the judgment of the competition. Roemmich and Sinning (1997)[27] observed a significant IGF-1 decrease in a group of adolescent fighters that undergo intense training associated to a restrictive diet, in order to lower their weight and compete in lower categories.

If, on one hand, there are positive adjustments on bone tissue related to physical exercise performed at a suitable intensity, on the other hand there may be negative reactions from overtraining. Stress fractures from repeated overload are common among adolescent athletes[18].

Thus, a number of factors should be considered when prescribing intense physical exercise, such as the physical maturity level of the individual, temporal differences of physical growth, the bone mass peak at the different sites, and the hormonal regulation of these processes.

As to females, one is concerned in assessing the role of metabolic changes required from strenuous physical activities on the reproductive hormonal system[28]. Studies have detected lower growth speed and less bone mineralization in female adolescents who practice high intensity sports that require full control of body weight, particularly gymnasts[29] and runners[30].

Olympic gymnastics imposes a training intensity oftentimes too marked, with ground reaction power that may reach 15 times the athlete's body weight[15]. Initiation in this sport typically occurs at childhood, and goes on throughout adolescence, when the athlete takes part in important national and international competitions[29].

Twenty-two young female Olympic gymnasts, aged 11 to 14 years, were followed in their training and compared to a group of girls of their age, which did not practice Olympic gymnastics, considered as controls. The results showed that the gymnasts had late menarche and high incidence of injuries, particularly on the lumbar spine, compared to the control group[29].

A group of 15 ballet dancers aged 12 to 15 years were followed for four years[28]. The author concluded that the high use of energy from physical training, an average of 16.8 h/week, might have caused an important modulation on the hypothalamus-pituitary axis in puberty, which, combined with a low proportion of body fat, has prolonged pre-pubertal stage and led to amenorrhea.

According to some authors, a late menarche is related to intense physical activity before puberty; therefore, there is a reduction in bone mass that may compromise potential growth, a mechanism not fully understood. According to Mantonelli *et al.* (2002)[32], apparently there is a relationship between menstrual disorders and decrease of bone mass due to low estrogen levels seen in athletes with amenorrhea.

However, these aspects are not exclusive to gymnasts, as investigations with athletes of different sports (tennis and swimming) showed late menarche, which is related to intense training. Even though a number of factors may influence the age of menarche, such as genetic predisposition, low weight and/or low percentage of body fat, dietary restrictions, and stress, it seems that overtraining is crucial for the assessment of this phenomenon among athletes[32].

Gremion *et al.* (2001)[30] stress that exhausting running training may also affect homeostasis of female sexual hormones, many a time causing secondary amenorrhea, high risk for osteopenia, and early bone fragility. For these investigators, amenorrhea is related to the intensity of training for running, to dietary restriction imposed to the athletes, to their low weight and thus, fat reduction.

Mantonelli *et al.* (2002)[32] report that amenorrhea and late menarche occasionally override the protective effect of physical exercise on bone mineralization. However, the negative effects on bone mineral density from high intensity exercises are not limited to females. Bilanin *et al.* (1989)[33] found a significant decrease in bone mineral density in long-distance male adolescent runners, with average traversed distance of 92 km ± 6.3/week, compared to non-runner adolescents.

The high intensity and huge training volume are typically seen in sports practiced by male adolescents, particularly sports involving muscle strength and power. Often adolescents seek to increase muscle mass by doing exercises with weights. This seeking for muscle enlargement requires close-to-maximum training overload[9]. Many a time, sports coaches prescribe strength training for adolescents and pre-adolescents, for them to achieve body hypertrophy, muscle power and/or shape, or just to improve body aspect[34].

The American Academy of Pediatrics (2001)[34] accepts the implementation of strength or endurance programs for children and adolescents. However, it suggests maximum lifting (one, two or three maximum repetitions) not to be carried out until adolescents are in maturity stage V of the sexual features, proposed by Marshall and Tanner. The concern for not performing maximum lifting is the possibility of injury of the epiphyseal plate, which is vulnerable before physiologic maturity.

Studies have shown that strength training, when properly structured as to the program's frequency, type, intensity and duration, may increase strength of pre-adolescents and adolescents[35]. This author reports that adolescents that undergo a strength training program may improve their motor skills, potentializing their fitness for specific sports, and becoming better prepared for competitions. However, further investigations with children and adolescents should be carried out, for assessment of chronic and acute training with weights on anatomic and physiological variables[35].

FINAL CONSIDERATIONS

Even though the literature shows the positive effects of sports on bone health, the prescription of the best suited physical exercises is quite controversial, both in intensity and duration, for enhancement of bone shaping.

When the prescription of physical exercises focuses adolescents, one should be very careful, as this stage of life is characterized by intense biologic changes, including growth in height, neuroendocrine maturation, the development of secondary sexual features, and marked changes of cardiovascular and musculoskeletal systems. Moreover, the big challenge for those who guide sports activities to young people is to convince them to keep a constant and appropriate intensity, and not go beyond their physiological limits; the adolescent typically wants to have immediate results, questions preestablished standards and has constant mood swings.

The increase of training intensity should be reasonable and coherent with the goals, and it should be safe and effective for each age group and biologic maturity of individuals, regardless of the competition calendars.

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