BONE MINERAL CONTENT AND BONE MINERAL DENSITY IN FEMALE SWIMMERS DURING THE TIME OF PEAK BONE MASS ATTAINMENT

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ABSTRACT: The aim of this study was to assess bone mineral content and bone mineral density in girls practising swimming in the period of peak bone mass attainment in comparison to girls at the same age who are not actively involved in sports. This study involved girls from sports school specialising in swimming (n=41) aged 11-15 years, practising swimming (non-weight bearing activities), and girls at the same age not actively involved in sports (n=45). The current condition of bones was assessed based on the method of densitometry DEXA (lumbar spine L2-L4). Data on sports careers, including the length of training and training load, and hormonal status were collected using a diagnostic survey with an especially developed questionnaire. The quantitative composition of diet was determined based on 3 individual interviews on dietary intake in the last 24 hours preceding the test. Analysis of the results showed that the average values of the measured bone parameters were not different between the groups. However, we observed a trend of higher values in the control group. In the assessment of diet, we observed in both groups a deficiency in average calcium intake. Based on the results it can be concluded that the tested female swimmers were not at increased risk of developing osteopenia, when compared to girls not actively involved in sports.

KEY WORDS: young female swimmers, bone mineral content and bone density, physical activity, intake of calcium

INTRODUCTION

Skeletal development is affected by many factors: genetic and environmental, such as physical activity and nutrition, hormones as well as numerous molecular factors. The human skeletal system provides support for the body. It is a place for muscle attachment, protection for all internal organs, and a store of calcium, phosphorus and magnesium. The human skeleton, depending on age, is subject to constant changes in bone mass. These include the phase of growth, consolidation and involution of bone tissue [16,20]. The period of childhood and puberty has a significant impact on bone mineral content. Rapid construction of skeleton takes place, which lasts until the closure of bone epiphysis, i.e. about 20 years of age. At that time, 90-95% of bone mass is formed [21]. Puberty is a critical period, as it is the time when about 40% of peak bone mass (PBM) accumulates. Essential elements of normal bone mineralization during this period are above all: proper pubescence, proper calcium intake and physical regular exercise, which determine such variables as increase in body height and muscle mass [11,14,17,26].

After reaching the maximum bone mineral content at the age of about 30-35 years, bone mass begins to decrease (minerals and collagen in the bone matrix are removed faster than new bone tissue is created). In the event of increased bone resorption there is a danger of osteopenia, which might finally result in osteoporosis. It is therefore extremely important that at the time when the skeleton reaches its full potential, PBM remains at optimal levels [1,24]

Osteoporosis in children is still an underestimated problem, despite the fact that the consequences of disorders in bone mineral content during the period of growth increase the risk of this disease in adulthood. However, we lack long-term observations and clinical studies on children who are in the period of attainment of peak bone mass, especially young girls actively involved in sports, who often at this age are already achieving sporting successes. It is emphasised that excessive physical activity at such a young age may be a factor causing disorders in bone metabolism [4,8].

Osteoporosis in children and adolescents is not a rare phenomenon. It may appear as a congenital bone defect or as a secondary phenomenon, which accompanies specific diseases. Primary disorders of the bone matrix are present in the case of osteogenesis imperfecta and idiopathic juvenile osteoporosis [34].

Girls attain approximately 80% of peak bone mass before the first menstruation. Half of this quantity is accumulated between 10 and 12 years of age, i.e. just before puberty. The remainder is accumulated at a very fast pace during puberty in the next 2-4 years. After puberty, this process slows down [10,13,20,39].

What factors are necessary to attain optimal peak bone mass? Undoubtedly, they include a diet with adequate calcium content (with an appropriate ratio of calcium to phosphorus consumed), vitamin D and protein, and exercise appropriate to the biological age, which if regularly performed increases mechanical stress of muscles on the bones. An important role in this process is also played by appropriate pubescence, which is determined by synthesis of oestradiol in girls and testosterone in boys, at an optimum level. Furthermore, it is necessary to eliminate factors disrupting normal development of bone tissue, such as chronic use of medication, nutrients, inadequate nutrition behaviour (reducing diets), as well as both insufficient and excessive physical activity [2,9,22,23,32].

Most of these recommendations should be strictly adhered to, especially by children and youths involved in competitive sports, and failure to meet these requirements should exclude them from competitive training. Densitometry is a diagnostic study providing quantifiable information on the risks of the process of ossification.

The population most vulnerable to the negative impact of dietary and hormonal disorders, as well as excessive physical burdens, is that of girls actively involved in competitive sports. Achieving PBM coincides in time with the greatest burdens, associated with success in sports, which may suggest disorders in bone tissue metabolism. This mainly applies to girls practising sporting disciplines – i.e. so-called non-weight bearing activities, which include swimming. Swimming is the discipline which arouses the most controversy about the beneficial or adverse effects of this type of physical activity on the condition of bone tissue.

Purpose of the study. The aim of this study was to assess bone mineral content (BMC) and bone density (BMD) in girls practising swimming during the time of peak bone mass attainment, as compared to girls at the same age, who are not actively involved in sports. The study also attempts to answer the following questions:

1. Is the training load used at such an important period of life (11-15 years) a threat to normal mineralization of bone tissue?
2. Does swimming as a discipline of sport promote or inhibit increase in mineralization, in view of the existing controversy about the beneficial impact of swimming on bone tissue?
3. Do diet and hormonal status of the tested subjects pose a risk to the proper development of bone tissue?

MATERIALS AND METHODS

The study included 86 girls aged 11-15 years, including 41 athletes from sporting schools involved in swimming (non-weight bearing activities), who represented a high sporting level. The control group consisted of girls at the same age, who were not involved in sports (n=45). Before testing, all the girls were subjected to medical examination, determining the overall health status and stage of development of sexual characteristics on the Tanner scale. Participation in the study was voluntary, to which consent was obtained from each of the girls and their parents. The project was approved by the Bioethics Commission of the University of Physical Education in Warsaw. The studies are of long-term nature, and the presented results concern the first stage of the study.

Body height and weight were determined in a conventional manner with accuracy up to 0.1 cm and 0.1 kg. The body fat content was determined according to the Durnin and Womersley method [7].

Bone mineral content BMC (g) and bone mineral density (BMD g/cm^2) were determined in the lumbar spine (L2-L4) by dual energy X-ray absorptiometry using Lunar DPX-L (USA) apparatus.

Information on sporting career including age when they started regular training, length of training, weekly training loads (in hours), hormonal status, i.e. gonadal function (menarche age, menstrual cycle types: regular, irregular, secondary amenorrhea), and dietary behaviour, was collected by way of diagnostic survey, using an especially developed questionnaire completed by parents of the tested children. The questionnaire also included questions regarding the prevalence of osteoporosis risk factors (environmental, genetic, health condition).

The quantitative composition of diet was determined based on 3 individual interviews on dietary intake in the last 24 hours preceding the test. The interviews included school days and days off (Sundays). In order to accurately determine the amount of food consumed we used the „Album of photographs of products and foods of different portion sizes" [37]. Consumption of energy, protein, fat and some minerals and vitamins in the daily food rations (DFR) was calculated using a computer program based on the current nutrition tables [19]. The results, taking into account 10% reduction due to the inevitable losses, were compared to the current standards of nutrition, taking into account the gender, age, body weight and physical activity of patients [15].

Statistical analysis of the results was performed on the basis of univariate analysis of variance (ANOVA).

RESULTS

Table 1 shows the anthropometric characteristics of the tested girls. The average age of girls practising swimming (n=41) was 11.5 years while that of the girls in the control group (n=45) was 12.0 years. Higher average body mass was characteristic for girls in the control group (45 kg), while the swimmers were lighter (40.7 kg). Similar relationships were observed for body height. In the control group the average value was 154.2 cm, while in the swimmers it was 148.9 cm. Also, higher average BMI and percentage body fat were found in the control group; they were respectively 18.7 kg/m^2 and 21.8%, and in the case of the swimmers 17.5 kg/m^2 and 20.9%.

Both tested groups were very similar in terms of anthropometric parameters, with no statistically significant differences appearing in any of the tested parameters. It was also found that the height and weight of the girls in each case were within the national standard [30].

TABLE 1. ANTHROPOMETRIC CHARACTERISTICS OF THE TESTED GIRLS ($\bar{x}$ ±SD)

GROUP	Number (n)	Age (years)	Body Mass (kg)	Body Height (cm)	BMI (kg/m²)	Fat Tissue (%)
Swimmers	41	11.5±0.97^{NS}	40.7±8.7^{NS}	148.9±17.3^{NS}	17.5±2.2^{NS}	20.9 ± 2.7^{NS}
Control group	45	12.0±0.76	45.0±10.3	154.2±9.4	18.7±3.4	21.8 ± 4.7

Note: ^{NS}-no significant p>0.05

TABLE 2. INFORMATION ON SPORTING CAREERS OF GIRLS ACTIVELY INVOLVED IN SWIMMING ($\bar{x}$ ± SD)

GROUP	Number (n)	Age when training commenced (Years)	Length of training (Years)	Weekly training load (hours)
Swimmers	41	8.75±1.03	2.4±1.2	12.0±3.2

Table 2 presents data on the sporting careers of girls practising swimming. On average, female swimmers began training at the age of about 9 years. The length of training of the tested swimmers was on average 2.4 years, with weekly training loads being at the level of 12 hours. 70% of training took place in the water, while the remaining 30% took place on the land (general and strength training). In the control group the girls devoted, on average, 4.2 hours per week to physical recreation.

The current condition of bone tissue of the tested girls is presented in Table 3. Average values of the described bone parameters were similar between the groups. However, we observed a trend of higher values in the control group, for both BMC (30.02 g) and BMD (0.921 g/cm^2), as compared to the group of swimmers, whose values were 26.59 g and 0.871 g/cm^2.

Individual analysis of the results showed that, according to criteria of the WHO (Z-score index), test results of as many as 12 of the girls (13.9%) (6-14.6% from the group of swimmers and 6-13.3% from the control group) showed low bone density in relation to the calendar age. The values of this index ranged from -1.9 to -2.7.

Analysis of the diets showed that the daily energy intake for girls practising swimming was 2520 ± 548 kcal, and in the case of those not involved in sports it was 2052 ± 416 kcal. The values differed significantly (p <0.001) and in the group of swimmers they were more than 23% higher than the average demand of the group. Also, large statistical differences in favour of the swimmers were found in total protein intake (80.4 ± 19.0 g vs. 63.4 ± 10.0 g, p <0.001), calcium (602 ± 229 mg vs. 454 ± 236 mg, p <0.01) and phosphorus (1390 ± 420 mg vs. 1027 ± 292 mg, p <0.001) (Table 4).

Intake of protein and phosphorus in the group of girls practising swimming and in the control group exceeded the average demand level of the group by 96% and 75% and 55% and 29%, whereas the consumption of calcium (in both groups) on average did not exceed 49% of normal sufficient consumption. Also, nutritional dietary density, calculated for calcium in the DFR as compared with the density calculated on the basis of the standards differed from the recommendations in both groups, and in the group of swimmers and in the control group it was respectively 44% and 35.7%.

Retrospective data about the frequency of consumption of milk and dairy products showed that 25% of girls in the control group consumed milk and milk products 2-3 times a day, in contrast to the swimmers, of whom only about 15% reported their consumption being so frequent. It seems to be comforting that about 50% of all the girls drink milk and consume dairy products on a daily basis (with different frequencies) and that there were no answers of „no consumption at all".

TABLE 3. SPECIFICATION OF BONE PARAMETERS IN THE TESTED GIRLS ($\bar{x}$ ±SD)

GROUP	Number (n)	BMC (g)	BMD (g/cm2)	As compared to age (%)
Swimmers	41	26.59±7.62^{NS}	0.871±0.127^{NS}	97.0±10.1^{NS}
Control group	45	30.02±10.50	0.921±0.176	98.1±15.6

TABLE 4. AVERAGE INTAKE OF ENERGY, PROTEIN, CALCIUM AND PHOSPHORUS BY THE TESTED GIRLS ($\bar{x}$ ±SD)

GROUP	Number (n)	Energy (kcal)	Protein (g)	Calcium (mg)	Phosphorus (mg)	Ca : P
Swimmers	41	2520±548 (123.1) #	80.4±19.0 (196.0)	602±229 (55.7)	1390±420 (174.6)	1: 2.3
Control group	45	2052±416*** (108.4)	63.4±10.0*** (155.0)	454±236** (41.0)	1027±292*** (128.6)	1: 2.3

Note: # in the case of energy, protein and phosphorus the value in brackets represents the average % of the norm realised as compared to the average group demand (EAR), and in the case of calcium the value in brackets represents the average deviation from sufficient intake (AT).
**p≤0.01, ***p≤0.001 value significantly lower than appropriate value for girls actively involved in swimming

Analysis of the degree of sexual maturity on the Tanner scale showed that approximately 70% of the girls were at stage III, 13% of the girls were at stage IV, and 17% of the girls were at stage V of maturation.

Gonadal function was analysed on the basis of appearance or lack of appearance of menarche and regular menstrual cycles. In the study group 15 girls from the control group (33.3%) and only 2 swimmers (4.8%) menstruated (for 1-2 years), but mostly it was irregular menstruation. Perhaps this is due to the fact that the control group consisted of older girls at the age when menarche occurs in the Polish population (12.73 years) [25].

The questionnaire also included questions about risk factors of osteoporosis, genetic as well as lifestyle-related. None of the girls in either of the groups had any osteoporosis history in the family. However, both in the group of athletes as well as in the control group there had been 5 (12.2%) and 6 (13.3%) prior fractures at different skeletal sites, which were the result of falls.

DISCUSSION

For a long time osteoporosis has been considered to be a disease of elderly people, but clinical observations have shown that the tendency to develop this disease appears as early as during the growth and development period. The risk of osteoporosis in adulthood, in fact, is predicted by the level of peak bone mass (80%) attained at the age of 18 years [14,27,35].

The mineral content in bone tissue grows during the period of puberty by 3-4% annually, while the pace of growth is different for the axial and peripheral skeleton. And so, in the case of the spine and the proximal segment of the femur it was found that the contents of minerals increased during this time 2.5 fold, while the content of minerals in the radius changes only slightly. The first three years of puberty are a critical period for the spine, which is due to increased production of sex hormones. By contrast, the growth of the limbs depends primarily on the impact of growth hormone. Bone mineral density is reduced during the transition period of accelerated growth (adolescent growth spurt), with the greatest disparity between the bone growth in length and the mineral accumulation being observed at the age of 11 years [15.23].

Most important for proper growth of bone mass in adolescence, in addition to genetic factors, is the synergistic effect of physical activity and nutrition (especially calcium intake). The most compelling evidence is provided by studies conducted in the period of attainment of peak bone mass. It is pointed out that properly chosen exercises, performed regularly over a long period of time (training), ensure the achievement of its optimum magnitude, preventing the development of osteoporosis at later stages of life [4,6,31].

Partfitt [28] concluded in his study that almost half of peak bone mass is accumulated in the first years of puberty during the period of active growth. At that time the greatest effect of physical exercise on bone mass is observed, and following that period this effect decreases. This is also confirmed by research results of other authors [4.36]. However, in the case of girls actively involved in sports, one cannot ignore the fact that while beneficial effects of sport do in fact exist, heavy loads of training can cause serious health disorders, which may result in low bone mass. The most commonly observed disorders include delayed age of menarche and irregular menstrual cycles as well as irregular diet [5,12,18].

An important issue for the mineralization process, as mentioned at the beginning, is the kind of physical stress to which the body is subjected, but it is believed that any physical activity (appropriate to the age) with repeated stress leads to increased bone density in the places subjected to the stress. However, the optimal form of physical activity, which has the greatest impact on bone mass, is resistance exercise with large stress on the skeleton (weight bearing activities) [4,29,33].

Snow-Harter and associates [36] observed a 1.2% increase in BMD in the lumbar spine (as compared to the control group) in women aged 16-21 years, after 8 months of resistance training.

Less favourable in this respect is training involving non-weight bearing activities, such as swimming. However, there is no convincing research evidence showing that swimming does not affect bone mass. Research conducted by Orwoll and associates [27] showed that women who used to practise swimming had better calcification of the spine than those in the corresponding age who never practised sports. Despite various objections, different authors agree that swimming is better for bone tissue than no activity at all [8,12,13]. However, it is believed that exercises associated with small loads do not affect bone density as favourably as those that relate to average loads (walking) or high loads (volleyball) [6].

In the studies presented, there was no beneficial effect of swimming on the evaluated bone parameters, but their values were consistent with the reference standards. The slightly lower average values observed in swimmers compared to the girls not actively involved in sports were statistically insignificant (Table 3). The result is likely to be explained by the lower body mass of swimmers as compared to the control group (Table 1). In addition, the control group consisted of slightly older girls, being at the age at which menarche occurs in the Polish population – 12.73 years (compare e.g. UK age 13 and USA age 13.75) [3,40]. The lower values of bone parameters in the swimmers could therefore be a reflection of their hormonal status. Most of the competitors (95%) had not yet menstruated, as compared to 70% of the girls in the control group, which implies low levels of oestrogen in the blood. Bone is one of the target tissues for oestrogen action that affects in various ways the metabolism of this tissue, including the maturation and activity of osteoblasts, the metabolism of vitamin D and calcium absorption in the intestine [9,24,32].

The results of research conducted by many authors point to the prevalence of calcium deficiency in the diet of school children, which also covers sports, and can be a cause of unsatisfactory bone mineral content, both in adolescence and in the subsequent periods of life [2,5,17,26,38]. Our study also indicated an inadequate supply of the DFR macro element in both the competitors and the girls from the control group, which was respectively 602±228.6 and 454±235.7 mg/day/person, which is only 55 and 41% of the average recommended intake for the group. Such nutrition habits may pose a real threat to health, and especially for proper bone mineral content and optimal level of peak bone mineral content.

Although the studies presented no evidence of reduced bone mineral content in swimmers, many clinical studies indicate that girls actively involved in sports may be one of the groups affected by increased risk of reduced bone mass. The presence of these risk factors during the many years of sporting activity may in fact undermine the beneficial effects of exercise on bones, especially during the period of attainment of peak bone mass [1,2,11,28].

It seems that the systematic evaluation of bone quality in young female athletes, especially swimmers, is therefore extremely important, and in this sporting group it should be part of periodic and routine medical examinations.

CONCLUSIONS

1. Analysis of the test results (BMC, BMD) showed that swimming training associated with heavy loads did not negatively affect the bone mineral density in the tested swimmers
2. Our results do not suggest that swimmers were a group of increased risk of osteopenia at later stages of life, provided that special attention is paid to diet (calcium intake) or early reaction to gonadal dysfunction.
3. Analysis of the diet points to the need for education of children and young people in this area.
4. It is recommended to increase the intake of calcium primarily in the form of milk and milk products, especially for athletes.

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