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Original research

Bone structure of adolescent swimmers; a peripheral quantitative computed tomography (pQCT) study

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ABSTRACT

Objectives: The aims of the present study were: (1) to characterize vBMD, bone structure and strength with peripheral quantitative computerized tomography (pQCT) in adolescent swimmers and compare it to normo-active controls (CG); and (2) to evaluate the possible interaction that weight-bearing sports might have on swimmers bone.
Design: Cross-sectional.
Methods: The non-dominant radius and tibia of 79 (32 females) swimmers and 49 (22 females) CG (both 11–18 years old) were evaluated at proximal and distal sites with a pQCT scanner. Values of total, trabecular and cortical volumetric bone mineral density (vBMD) were obtained from each scan. Cortical thickness, endosteal and periosteal circumferences were also measured and bone strength indexes were calculated. Analyses of covariance were used to compare variables between groups adjusting for age, tanner stage and bone length. Three different analyses were performed according to present and past sport participation in addition to swimming in order to determine differences among swimmers who had performed or were performing other sports (OTHER-SP) (10 females/17 males) and swimmers who had not performed other sports (NO-OTHER-SP) (22 females/22 males). Both of these groups were compared to each other and to a CG (22 females/27 males).
Results: No differences were found between swimmers and CG for bone strength indexes, structure or vBMD (independently of the compared sample).
Conclusions: These results indicate that swimmers present similar bone strength and structure than CG who did not present high physical activity levels.

1. Introduction

Osteoporosis is a worldwide disease producing huge social and economic costs.[1] Peak bone mass accumulation occurs around 12–14 years, being bone mineral content (BMC) accumulation greater in active children.[2] Thus, physical activity and sport engagement become extremely important during adolescence, when bones are more responsive to weight-bearing activities.[2] Bone mass improvements are thought to be mainly related to geometric adaptations.[3] Thus, the measurement of bone structure becomes essential.

Nevertheless, no studies have been performed in adolescent swimmers evaluating bone structure with peripheral quantitative computerized tomography (pQCT), and those performed in adults have shown that swimmers present no differences when compared to their sedentary peers (for review[4]). Most of the studies evaluating bone strength in adult swimmers were performed with pQCT that measures volumetric bone mineral density (vBMD) and bone geometry. From the cross sectional geometry, pQCT software calculates several strength indexes, which have been reported to give a better estimation of bone strength than bone mass measured by DXA.[5] To our knowledge, this technique has been performed in six studies with swimmers[6–11] using just one high resolution pQCT.[11]

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Overall they showed that swimmers presented weaker bones when compared to athletes in weight-bearing sports[7,8] as a result of smaller cross-sectional areas, but swimmers presented similar[7,8,11] and higher[6,9] bone strength values than sedentary controls. Nevertheless, bone may adapt to the characteristics of swimming, resulting in similar or higher bone strength indexes than in sedentary peers, making it more resistant to bending and torsion, even though it may have lower BMD.[4] It has also been hypothesized that previous or current sports participation by swimmers could also be a key to bone mass.[12]

Bone structure in adolescence can influence bone health in adulthood[13] thus it is important to determine the effects of swimming during adolescence on bone structure. Several studies found no differences in bone structure in adolescent swimmers compared to CG using hip structural analysis,[4] which when applied to DXA images, estimates structural parameters at the femur. Due to the previous DXA findings in adolescent swimmers[12] that found lower aBMD values in swimmers than CG, we hypothesized that adolescent swimmers would present weaker bones.

Therefore, the main aims of the present study were: (1) to evaluate bone parameters using pQCT in adolescent swimmers and healthy normo-active controls (CG); (2) to study whether if those swimmers who were currently performing or had performed weight-bearing sports in addition to swimming presented higher bone strength or structure values.

2. Methods

To be included in the study, participants had to be between 11 and 18 years old, Caucasian, healthy, training for a minimum of 6 h per week and competing in regional tournaments for at least 3 years. Participants in the CG could not be performing any aquatic activity and could not be engaged in any sporting activity for more than 3 h per week.

Written informed consent was obtained from parents and assent from the adolescents. The study was performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Edinburgh 2000). The protocol study was approved by the Ethics Committee of Clinical Research from the Government of Aragón (ref. CP08/2012, CEICA, Spain).

Height was measured with a stadiometer without shoes and the minimum clothes to the nearest 0.1 cm (SECA 225, SECA, Hamburg, Germany) and weight to the nearest 0.1 kg (SECA 861, SECA, Hamburg, Germany). For the radius scans, the length of the bone from humeroradial joint cleft to the styloid process was measured using a ruler (to the nearest 0.1 cm). For the tibia scans, the length of the bone from the distal end of the medial malleolus to the medial knee joint cleft was measured.

Pubertal maturation was determined by self-assessment of secondary sexual characteristics according to the five stages proposed by Tanner et **al.**[14]

Milligrams of daily calcium intake were calculated from a calcium food frequency questionnaire.[15] In addition, current and past sport participation was assessed by interviewing the adolescent. All swimmers (ALL-SW) were considered as a group (ALL-SW: 32 females/39 males). However, as some of the swimmers were engaged or had been engaged in other sports in addition to swimming, ALL-SW were divided into two groups. The first group (OTHER-SP) consisted of swimmers who were doing weight-bearing sports more than 2 h per week and/or had done other weight-bearing sports for a period of more than 2 years in the past. The second group (NO-OTHER-SP: 22 females/22 males), consisted of swimmers who did not currently perform any other sports and had not performed any other sports in the past (no more than 3 h per week or two years of a different sport).

A Stratec XCT-2000 L scanner (Stratec Medizintechnik, Pforzheim, Germany) was used in order to evaluate bone, lean and fat mass. Scanning procedure in our laboratory has been described in detail elsewhere.[16,17] The dominant limbs were determined by asking the participants which hand they used to write and which leg they used to kick a ball. Once the dominant limbs were determined the non-dominant upper and lower limbs were measured as recommended by the International Society for Clinical Densitometry.[18] The measurement sites for the radius were located proximal to a reference line by a distance corresponding to 4% (distal radius) and 66% (diaphyseal radius) of the forearm length and 4% (distal tibia) and 38% (diaphyseal tibia) of the tibia. For lower limb muscle and subcutaneous fat the measurement site was at 66% of the length of the tibia. For the upper limb the muscle and subcutaneous fat were measured at the 66% of the length of the radius. At the 4% site of the radius and tibia total and trabecular cross-sectional bone area (mm^2); vBMD (mg/cm^3); total vBMD (TOT_vBMD) and trabecular vBMD (TRAB_vBMD) were evaluated. At the 66% site of the radius and 38% site of the tibia total and cortical bone cross-sectional area (mm^2); TOT_vBMD and cortical vBMD (CRT_vBMD) were measured. Cortical thickness (CRT_THK, mm), endosteal circumference (ENDO_CIR, mm) and periosteal circumference (PERI_CIR, mm) were also measured at these sites. Bone strength was established with respect to torsion (SSI, polar stress strain index, mm^3), and bending (fracture load, N) with respect to the X-axis. All the strength indexes were calculated at diaphyseal sites of the radius and tibia.

As the present study is part of the RENACIMIENTO Project[17] which was designed to elucidate the effect of swimming on bone accretion in swimmers between 12 and 18 years of age, the sample size of the project was designed according to the primary study variable that was whole body BMD. A bilateral student t-test was used to test the null hypothesis H0: $\mu 1 = \mu 2$, assuming that the mean in the swimming group is 0.991 units (data obtained from a pilot study with 17 swimmers) and is 1.127 units in the control group (data obtained from European adolescents[19]) with a standard deviation of 0.1 units in each group. A total of 10 experimental units in each group were needed for achieving a power of 80% with a 95% confidence.

SPSS for Windows version 15.0 (SPSS, Inc, Chicago, IL) was used to analyze the data. All analyses were stratified by sex. One-way analyses of variance (ANOVA) with least significant difference *post hoc* were performed for these variables in order to examine differences among groups. Cross-tabs applying Chi square tests were used to test differences between groups for Tanner status. One-way analyses of covariance (ANCOVA) using the Bonferroni method to correct for multiple *post hoc* comparisons were performed to compare bone strength and geometry variables. Following the 2007 ISCD Pediatric Official Positions[18] data were adjusted by bone length, as bone size and geometry are proportional to the length of the bone. Pubertal status was also a covariate of adjustment, as density of the distal radius increases with menarche in girls and as puberty progresses in boys. Age was also introduced as a covariate. All the ANOVAS and ANCOVAS examined differences between the three different groups of swimmers versus CG; ALL-SW vs controls; OTHER-SP vs controls; NO-OTHER-SP vs controls and OTHER-SP vs NO-OTHER-SP. Further ANCOVAS were performed including limb cross-sectional muscle area (MCSA) in order to account for the influences of muscle on bone. Finally, calcium intake was also used for adjusting ANCOVAS in order to account for the influence of diet on bone.

3. Results

A total of 187 participants signed the informed consent and agreed to participate in the study (98 swimmers). A total of 71