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Peripubertal female athletes in high-impact sports show improved bone mass acquisition and bone geometry

Laurent Maïmoun[a,b,*], Olivier Coste[a,c], Pascal Philibert[a], Karine Briot[d], Thibault Mura[e,f], Florence Galtier[f,g], Denis Mariano-Goulart[h], Françoise Paris[a,i], Charles Sultan[a,i]

[a] Département d'Hormonologie, Hôpital Lapeyronie, CHU Montpellier, 191 avenue Doyen Gaston Giraud, 34295 Montpellier, France
[b] Service de Médecine Nucléaire, Hôpital Lapeyronie, CHRU Montpellier, France and UMI and Physiologie & médecine expérimentale du Cœur et des Muscles - INSERM - U1046, Montpellier, France
[c] Direction Régionale de la Jeunesse, des Sports et de la Cohésion Sociale, Montpellier, France
[d] Service de Rhumatologie, Hôpital Cochin, APHP Paris, France
[e] Centre d'Investigation Clinique et Département d'Information Médicale, CHRU Montpellier, Montpellier, France
[f] CIC 1001, INSERM, Montpellier, France
[g] Centre d'Investigation Clinique et Département des Maladies Endocriniennes, CHRU Montpellier, Montpellier, France
[h] Service de Médecine Nucléaire, Hôpital Lapeyronie, CHRU Montpellier, France
[i] Unité d'Endocrinologie Pédiatrique, Hôpital Arnaud de Villeneuve, CHRU Montpellier et UMI, Montpellier, France

ARTICLE INFO

Article history:
Received 24 July 2012
Accepted 29 November 2012

Keywords:
Bone mass acquisition
Intensive training
Growth period
Markers of bone turnover
OPG/RANKL system

ABSTRACT

Objective. Intensive physical training may have a sport-dependent effect on bone mass acquisition. This cross-sectional study evaluated bone mass acquisition in girls practicing sports that put different mechanical loads on bone.

Materials/Methods. Eighty girls from 10.7 to 18.0 years old (mean 13.83 ± 1.97) were recruited: 20 artistic gymnasts (AG; high-impact activity), 20 rhythmic gymnasts (RG; medium-impact activity), 20 swimmers (SW, no-impact activity), and 20 age-matched controls (CON; leisure physical activity <3 h/wk). Areal bone mineral density (aBMD) was determined using DEXA. Hip structural analysis applied at the femur evaluated cross-sectional area (CSA, cm^2), section modulus (Z, cm^3), and buckling ratio. Bone turnover markers and OPG/RANKL levels were analyzed.

Results. AG had higher aBMD than SW and CON at all bone sites and higher values than RG in the lumbar spine and radius. RG had higher aBMD than SW and CON only in the femoral region. CSA and mean cortical thickness were significantly higher and the buckling ratio was significantly lower in both gymnast groups compared with SW and CON. In RG only, endocortical diameter and width were reduced, while Z was only increased in AG compared with SW and CON. Reduced bone remodeling was observed in RG compared with AG only when groups were subdivided according to menarcheal status. All groups showed similar OPG concentrations, while RANKL concentrations increased with age and were decreased in SW.

Abbreviations: aBMD, areal bone mineral density; AG, artistic gymnasts; BMI, body mass index; CON, controls; CSA, bone cross-sectional area; CSMI, cross-sectional moment of inertia; CTX, type I-C telopeptide breakdown products; DEXA, dual-energy x-ray absorptiometry; FFST, fat-free soft tissue; FM, fat mass; HAS, hip structural analysis; IT, intertrochanteric; L1-L4, lumbar spine; NN, narrow-neck; OC, osteocalcin; OPG, osteoprotegerin; PINP, procollagen type I N-terminal propeptide; RANKL, rank-ligand; RG, rhythmic gymnasts; SW, swimmers; TPF, total proximal femur; WB, whole body; Z, section modulus.

* *Corresponding author.* Département d'Hormonologie, Hôpital Lapeyronie, CHU Montpellier, 191 avenue Doyen Gaston Giraud, 34295 Montpellier, France. Tel.: +33 467 79 99; fax: +33 467 33 83 27.
E-mail addresses: l-maimoun@chu-montpellier.fr, laurent.maimoun@laposte.net (L. Maïmoun).

0026-0495/$ – see front matter
http://dx.doi.org/10.1016/j.metabol.2012.11.010

Conclusion. High-impact activity clearly had a favorable effect on aBMD and bone geometry during the growth period, although the bone health benefits seem to be more marked after menarche.

1. Introduction

Among the environmental factors that affect bone mass acquisition, physical activity plays a crucial role. Although its mode of action is not fully understood, it is generally assumed that mechanical loading is an important determinant of skeletal growth and modeling [1]. Weight-bearing activities are more beneficial for bone mass acquisition in childhood than no-impact and non-weight bearing activities [2,3]. These findings are mainly based on areal bone mineral density (aBMD) as evaluated by dual-energy x-ray absorptiometry (DEXA) scans, and less is known about the potential effects of exercise on bone microarchitecture and geometry, two parameters implicated in bone strength [4,5]. Studies using newer technologies, such as peripheral quantitative computed tomography (pQCT), which provides more detailed information about changes in cortical bone geometry and strength, are now available.

In adolescents, Sayers et al. [6] reported that regular physical activity like jogging was positively associated with cortical bone mass compared with less intense exercise like walking. The increase in cortical mass is due to increased periosteal and reduced endosteal circumferences, an adaptation that may improve mechanical bone strength [6]. Using an indirect method (hip structural analysis, HSA software) based on DXA analysis [7], we recently reported higher mean cortical thickness in the femur of young artistic gymnasts than in non-athlete subjects, and this bone adaptation was observed throughout the growth period [8]. However, artistic gymnastics generates high specific mechanical strains [9], and we do not currently know whether bone geometry gradually adapts to mechanical strain according to the type of sport, as previously reported for aBMD [3,10,11]. Moreover, the same aBMD may correspond to different bone geometry models. Ferry's study [12] provided some elucidation: they found a concomitant favorable effect on BMD and bone geometry in female adolescents playing soccer, a high-impact sport [11], as compared with swimming, a no-impact sport [3,11].

These preliminary results on bone geometry should be confirmed in a range of sports generating different degrees of mechanical loading throughout the growth period, because age is a potential modulator of bone response [8,13]. A further consideration is that physical activity may also modulate bone remodeling [8,14] and the osteoprotegerin (OPG)/rank-ligand (RANKL) system [8,15,16], in addition to its effects on aBMD and bone geometry. These data are still controversial, however, and it remains to be demonstrated whether different types of sports generate specific profiles.

The aim of this cross-sectional study was to compare the bone mass acquisition in young girls performing sports that generate different mechanical loads. We included data from a population of artistic gymnasts [8], as this sport is a high-impact activity and the data helped us to determine the gradation in bone adaptation due to two other sports, rhythmic gymnastics (medium-impact) and swimming (low-impact). The bone adaptation was concomitantly evaluated by bone mineral density, bone geometry at the femoral region, bone remodeling markers, and the OPG/RANKL system.

2. Materials and methods

2.1. *Subjects*

The study protocol was reviewed and approved by the Regional Research Ethics Committee (CPP Sud-Mediterranee IV, Montpellier, France), and each child and her parents gave written informed consent before entering the study. A total of 80 girls with ages ranging from 10.7 to 18.0 years (mean 13.83 ± 1.97) were recruited for this study: 20 artistic gymnasts (AG), for whom part of the findings were previously reported [8], 20 rhythmic gymnasts (RG), 20 swimmers (SW), and 20 controls (CON). All athletes and controls were age-paired. The inclusion criteria were the following: The three sports groups were composed of girls training more than 8 h per week and who had been practicing their sport for more than 5 years. Each sport was chosen according to the mechanical loading that it generates (high for AG, medium for RG, and low for SW). Moreover, although AG and RG seem to be very similar sports (high-volume training, high prevalence of menstrual disorders), they differ in terms of the intensity and sites of the mechanical loading, as well as the individual growth potential [17,18]. The control group consisted of subjects who performed only leisure physical activities for fewer than 3 h per week, and none of these subjects had a history of participation in intense sports training.

The exclusion criteria were as follows: obvious signs of acute or chronic illness known to affect bone health and long periods of immobilization or fractures within the previous 12 months.

2.2. *Methods*

The design of this cross-sectional and case–control study has been described in detail [8]. Standing height was measured with a stadiometer to the nearest 0.1 cm. Weight was determined using a weight scale with a precision of 0.1 kg. Body mass index (BMI) was calculated as weight (kg) divided by the square of height (m). Pubertal development was assessed by breast stage (I to V) according to the Tanner classification [19] by an experienced pediatric endocrinologist. Skeletal age was determined using the Greulich and Pyle method [20].

Information regarding pubertal onset in family members was obtained from a standardized questionnaire (menarche of mothers). Height standard deviation score (height SDS) and