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History of amenorrhoea compromises some of the exercise-induced benefits in cortical and trabecular bone in the peripheral and axial skeleton: A study in retired elite gymnasts

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ABSTRACT

Background: Female gymnasts frequently present with overt signs of hypoestrogenism, such as late menarche or menstrual dysfunction. The objective was to investigate the impact of history of amenorrhoea on the exercise-induced skeletal benefits in bone geometry and volumetric density in retired elite gymnasts.
Subjects and methods: 24 retired artistic gymnasts, aged 17–36 years, who had been training for at least 15 h/week at the peak of their career and had been retired for 3–18 years were recruited. They had not been engaged in more than 2 h/week of regular physical activity since retirement. Former gymnasts who reported history of amenorrhoea ('AME', $n=12$: either primary or secondary amenorrhoea) were compared with former gymnasts ('NO-AME', $n=12$) and controls ('C', $n=26$) who did not report history of amenorrhoea. Bone mineral content (BMC), total bone area (ToA) and total volumetric density (ToD) were measured by pQCT at the radius and tibia (4% and 66%). Trabecular volumetric density (TrD) and bone strength index (BSI) were measured at the 4% sites. Cortical area (CoA), cortical thickness (CoTh), medullary area (MedA), cortical volumetric density (CoD), stress–strain index (SSI) and muscle and fat area were measured at the 66% sites. Spinal BMC, areal BMD and bone mineral apparent density (BMAD) were measured by DXA.
Results: Menarcheal age was delayed in AME when compared to NO-AME (16.4 ± 0.5 years vs. 13.3 ± 0.4 years, $p<0.001$). No differences were detected between AME and C for height-adjusted spinal BMC, aBMD and BMAD, TrD and BSI at the distal radius and tibia, CoA at the proximal radius, whereas these parameters were greater in NO-AME than C ($p<0.05$–0.005). AME had lower TrD and BSI at the distal radius, and lower spinal BMAD than NO-AME ($p<0.05$) but they had greater ToA at the distal radius ($p<0.05$).
Conclusion: Greater spinal BMC, aBMD and BMAD as well as trabecular volumetric density and bone strength in the peripheral skeleton were found in former gymnasts without a history of menstrual dysfunction but not in those who reported either primary or secondary amenorrhoea. History of amenorrhoea may have compromised some of the skeletal benefits associated with high-impact gymnastics training.

Introduction

Female gymnasts frequently present with overt signs of hypoestrogenism, such as late menarche [1–5] or menstrual dysfunction. Primary amenorrhoea was found in approximately 15–20% of elite female gymnasts [1,6,7], while episodes of secondary amenorrhoea were reported in 40–60% of this population [7–9].

In normally active women, late menarche was shown to be associated with slightly greater bone size [10], but lower volumetric trabecular density [11,12] and thinner cortices [10,13]. On the other hand, amenorrhoea and oligomenorrhoea were found to be associated with lower spinal areal bone mineral density (aBMD) in adolescent girls [14] and non-athletic premenopausal women [15]. In early pubertal girls, estrogen levels are negatively associated with the size of marrow cavity and positively associated with cortical thickness [16]. These findings suggest that low estrogen levels favour periosteal expansion while reducing endocortical apposition and trabecular volumetric bone density in growing girls.

Hypoestrogenism was also shown to have detrimental impact on the exercise-induced gains in bone mass in runners and ballet dancers. Although amenorrhoeic athletes may present with aBMD within normal range at loaded sites (e.g. hip) [17–20], spinal aBMD does not seem to benefit from such activities in the presence of menstrual irregularities [17–24]. Some amenorrhoeic athletes even presented with lower spinal aBMD than non-active girls or women [21,25,26].

Despite having late menarche and/or episodes of amenorrhoea, late adolescent and young adult gymnasts were shown to have greater

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aBMD than normally active females [6,7,27] or females engaged in less osteogenic activities such as running [7] or volley-ball [27]. It was therefore suggested that high-impact exercise such as gymnastics could offset the detrimental effect of hypoestrogenism through the production of ground reaction forces of a large magnitude — up to 11 times body weight [28,29].

However, previous investigations were conducted by dual-energy X-ray absorptiometry (DXA). DXA-derived aBMD is affected by several systematic and non-systematic errors: body size of the subject [30], fat/lean ratio of the surrounding soft tissue [31], and inhomogeneities of the surrounding soft tissue [32]. In contrast, three-dimensional bone imaging techniques such as peripheral quantitative computed tomography (pQCT) allow investigating the exercise-induced changes in bone geometry and volumetric bone density. This technology was used to compare female gymnasts with normally active girls, showing that the gymnasts had bigger bones in the upper limbs [33], greater cortical area [33] and higher volumetric trabecular density in the upper and lower limbs [33,34]. Because these gymnasts were pre- or early pubertal, aged 6–11 years, the influence of primary or secondary amenorrhoea could not be investigated.

It might be more appropriate to recruit retired gymnasts in order to investigate the effects of hypoestrogenism on bone health. Former artistic gymnasts who retired from competitive training for 8–24 years were shown to have significantly higher aBMD values compared with non-athletic controls, with differences ranging from 6 to 22% [3,5,35–37]. None of the studies which investigated the influence of menstrual dysfunction could detect a significant difference between gymnasts who experienced amenorrhoea and those who did not [5,36].

We previously reported that the exercise-induced skeletal benefits in cortical bone geometry and trabecular volumetric bone density could be maintained several years after retirement in former elite gymnasts despite a marked decrease in physical activity [38]. The objective of the present study was to investigate the impact of history of amenorrhoea on these skeletal benefits in the axial and peripheral skeleton. We hypothesized that history of amenorrhoea would be associated with greater outer bone diameter but also larger medullary cavity, thinner cortices and lower trabecular volumetric bone density in retired elite gymnasts.

Materials and methods

Subjects

A total of 55 premenopausal female subjects were recruited for this study, consisting of 25 retired artistic gymnasts (age range: 17–36 years) and 30 controls of similar age (age range 18–44 years). Inclusion criteria for the retired gymnasts were: 1) participation in high-level, competitive gymnastics during growth (childhood and adolescence) for at least four years, training for a minimum of 15 h/week at the peak of their career; 2) retirement from the sport for at least three years; and 3) participation in no more than 2 h/week of regular physical activity since retirement. Inclusion criteria for the controls were participation in no more than 2 h/week of regular physical activity during growth and adulthood. Furthermore, both groups were required to have no history of disease known to affect bone health and no recent long-term periods of bed-rest or limb immobilisation.

Subjects were recruited through Gymnastics Australia, staff and students of Deakin University and word of mouth. The Deakin University Human Research Ethics Committee for the Faculty of Health, Medicine, Nursing and Behavioural Sciences approved the study, and written consent was obtained from all participants. All experiments were undertaken in compliance with national legislation and the Code of Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association.

Medical questionnaire and history of training

Data on menstrual history and age at menarche were collected by questionnaire. Gymnasts were classified into two groups according to their menstrual history: those who ever had primary amenorrhoea or episodes of secondary amenorrhoea (AME) and those who did not report any history of amenorrhoea (NO-AME). Primary amenorrhoea was defined as the failure to menstruate by the age of 15 years [39]. Secondary amenorrhoea was defined as the absence of menses for 3 months or more after menarche [40–42].

The questionnaire was also used to collect information on the use of contraceptives, fracture history, as well as past and present activity status. In gymnasts, further questions included: age at onset of gymnastics training, interruptions to their gymnastics career, intensity and duration of gymnastics training (number of sessions/hours of training completed per week and level of competition), and age at retirement from gymnastics training.

Anthropometric measurements

Body weight was measured on a balance scale to the nearest 0.05 kg, in light clothing and without footwear. Standing height was measured using a stadiometer to the nearest 0.1 cm. Participants were asked about dominance of hand and consequently the limbs to be measured were determined as the nondominant arm and the contralateral leg (except if a fracture had occurred within the last 5 years, then the other limb was used).

Peripheral quantitative computed tomography (pQCT)

Bone parameters, estimates of bone strength and regional body composition of the forearm and lower leg were measured using peripheral quantitative computed tomography (Stratec XCT-3000 scanner, Stratec Medical, Pforzheim, Germany). This apparatus measures attenuation of X-rays which are linearly transformed into hydroxylapatite (HA) densities. The Stratec XCT 3000 is calibrated with respect to water which is set at 60 mg hydroxylapatit (HA), so that fat results in 0 mg HA [43]. HA equivalent densities are automatically calculated from the attenuation coefficients by employing the manufacturer's phantom which itself is calibrated with respect to the European Forearm Phantom (EFP; QRM, Erlangen, Germany) [43].

The scanner was positioned on the nondominant distal forearm and contralateral distal lower leg. A coronal computed radiograph (scout view) was carried out at each site. The scout view was used to position the reference line at the measurement site. At the radius, the reference line was perpendicular to scanning direction and was positioned on the lateral, most horizontal part of the radius distal endplate (automatic placement provided by the manufacturer). At the tibia, the reference line was placed on the medial portion of the distal endplate.

Forearm length was measured from the tip of the olecranon process to the most distal end of the ulna styloid process using a metal measuring tape (precision: 0.5 cm). Two pQCT scans were performed at 4% and 66% of the forearm length, proximal to the ulnar styloid process [44,45].

Tibial length was measured from the distal end of the medial malleolus to the superior aspect of the medial tibial condyle. Two pQCT scans were performed at 4% and 66% of the tibial length, proximal to the medial malleolus of the tibia [46].

Slice thickness was 2 mm, and voxel size was set at 0.5 mm with a scanning speed of 20 mm/s. Image processing and calculation of numerical values were performed using the manufacturer's software package (version 6, Stratec Medical, Pforzheim, Germany). Using various edge detection and thresholding steps, the pQCT image can be segmented into various bone and soft tissue measures as described below.