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Original article

Competitive trampolining influences trabecular bone structure, bone size, and bone strength

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Abstract

Background: Trampolining is a form of gymnastics that has increased in popularity over the last decade and due to its concurrence with the formative years of bone development, it may have an important impact on bone health. However, bone density, microarchitecture, and bone strength of competitive trampolinists have not been explored. Therefore, the purpose of this cross-sectional study was to investigate the relationship between trampolining participation and (1) bone density, area, and microarchitecture; and (2) estimated bone strength and the role of muscle and impact loading in young female adults.

Methods: We recruited 29 female participants aged 16–29 years for this study ($n = 14$ trampolinists; $n = 15$ controls). Skeletal parameters were assessed using dual X-ray absorptiometry, high-resolution peripheral quantitative computed tomography (HR-pQCT), and finite element analysis (FEA). Muscle strength was measured using dynamometers.

Results: Trampolinists had higher bone density at the hip and spine, greater trabecular density and thicker trabeculae at the tibia, as well as larger bones at both the tibia and radius than controls ($p < 0.05$). Trampolinists also had higher muscle strength than controls at the lower body with no difference between groups in the upper body. Estimates of bone strength using FEA were greater for trampolinists than controls at both the radius and tibia.

Conclusion: This is the first study to investigate bone density, area, and microarchitecture in female trampolinists using HR-pQCT. Trampolinists had greater bone density, area, microarchitecture, and estimated bone strength than controls.

Keywords: Dual X-ray absorptiometry; Finite element analysis; Gymnastics; High-resolution peripheral quantitative computed tomography; Muscle strength; Trampolining

1. Introduction

Trampolining is 1 of 7 gymnastics disciplines consisting of men's and women's artistic gymnastics, rhythmic gymnastics, aerobics, acrobatics, and gymnastics for all (general gymnastics combining all disciplines in a fun non-competitive environment). Specifically, trampolining consists of individual trampoline, synchronized trampoline, double mini-trampoline, and tumbling. In the year 2000 trampolining became an Olympic sport; however, Olympic competition only involves individual trampoline[1] and does not include 3 additional forms of trampolining. Nevertheless, as a result of its inclusion in the Olympics, trampolining has increased in popularity over the past decade.[1] Popularity has increased at both an unstructured "free-play" (backyard) level as well as in structured form at local gymnastics centers.[2]

Most of the scientific literature on trampolining highlights the injuries associated with both unstructured and structured involvement in the sport.[2–5] However, health benefits including enhanced strength, endurance, balance, and proprioceptive development following involvement in trampolining are also important aspects of the sport.[2,6] At a clinical level, trampolines have been used to increase maximal oxygen uptake in children with cystic fibrosis,[7] to improve motor and balance ability in children with intellectual disability,[8] and to enhance hip moment and balance during forward falls in an elderly cohort.[9] At a competitive level, the physiological responses and fatigue patterns of elite male trampoline athletes have been explored.[10] However, bone density, microarchitecture, and bone strength of competitive trampolinists are not known. Therefore, the aim of this study was to

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investigate the relationship between trampolining gymnastics participation and (1) bone density, area, and microarchitecture; and (2) estimated bone strength and the role of muscle and impact loading in young adult females.

2. Materials and methods

2.1. Participants

We recruited 29 female participants aged 16–29 years for this cross-sectional study over a 9-month period. Sample size was based on large effect sizes previously reported in gymnastics studies.[11] To achieve over 80% statistical power a minimum of 14 participants per group was required.[12,13] Trampolinists ($n = 14$) were training and competing at a provincial or national level. Controls ($n = 15$) were female sedentary volunteers recruited using information flyers from the student population at the University of Calgary. Controls have no previous or current training history in any competitive or organized sporting programs. Participants were healthy individuals with no medical conditions known to effect bone metabolism. Approval for all procedures was obtained from the University of Calgary Conjoint Health Research Ethics Board. All participants over the age of 18 years provided written informed consent prior to involvement in the study. For those participants under 18 years, a parent provided written informed consent on behalf of the child.

2.2. Anthropometrics

Height (Seca model 222; Seca, Hamburg, Germany) and weight (Seca model 876; Seca) were measured using standard protocols to the nearest 0.1 cm and 0.1 kg, respectively. Dual X-ray absorptiometry (DXA, Discovery A, Hologic Inc., Bedford, MA, USA) was used to obtain a measurement of lean mass (kg) and percent body fat (%) from a whole-body scan.

2.3. Health, physical activity, and calcium

All participants completed a series of questionnaires to assess their overall health and well-being. The short version of the International Physical Activity Questionnaire, a reliable and valid questionnaire[14,15] was used to determine general physical activity. Trampolinists completed a training history questionnaire to capture their weekly training commitments (training volume) and training age. To capture calcium intake, all participants completed a food frequency questionnaire (FFQ). The FFQ has been used by the Canadian Multi-Centre Osteoporosis Study,[16] which is a modified version of the Block et al.[17] (short form) and Willett et al.[18] questionnaires; however, has not been validated in an independent study.

2.4. Skeletal parameters

Both the dominant and non-dominant limbs were scanned as part of this study. Differences between limbs were not detected and as a result the dominant limb has been reported in this manuscript.

2.4.1. DXA

Areal bone mineral density (aBMD, g/cm^2) of the dominant hip (femoral neck (FN) and total hip (TH)), and lumbar spine (LS, L1–L4) was obtained by DXA. Controls were scanned on their dominant hip identified as the leg used to kick a ball, whereas trampolinists were scanned on their sport-specific dominant hip determined as the takeoff leg (push leg or last leg to leave the ground) in a hurdle. Machine calibration, daily and weekly quality assurance assessments were performed and monitored as per the manufacturer guidelines. All scans were performed and analyzed by 1 trained technologist (ISCD certified).

2.4.2. High-resolution peripheral quantitative computed tomography (HR-pQCT)

To assess measurements of volumetric bone mineral density (BMD, mg HA/cm^3), and bone macro- and micro-architecture of the peripheral skeleton, participants received an HR-pQCT scan (XtremeCT, Scanco Medical, Brüttisellen, Switzerland) of their radius and tibia. Controls were scanned on their dominant radius and tibia, whereas trampolinists were scanned on their sport-specific dominant radius and tibia determined by the "push" or second hand in a cartwheel and the takeoff leg in a hurdle. The opposite limb was scanned if a previous fracture was reported ($n = 1$ trampolinist; $n = 1$ control).

Participants were scanned using a standard human *in vivo* scanning protocol (60 kVp, 1000 µA, 100 ms integration time). Following a scout scan, reference lines were placed at the mid-inclination tuberosity and at the plateau portion of the tibial endplate, for the radius and tibia, respectively.[19] Each scan was comprised of 110 slices, corresponding to a 9.02 mm scan area, with a nominal isotropic resolution of 82 µm carried out at the standard location 9.5 mm (radius) and 22.5 mm (tibia) proximal to the reference line. Trained technologist performed and analyzed all scans using the standard manufacturer's method.[20] Scans were graded for motion artifacts: a scan scoring 1 had no motion, and a scan scoring 5 was subject to severe blurring and discontinuities.[21] None of our scan data had to be removed due to motion artifacts (motion score of 4 or higher) or inadequate scan quality. HR-pQCT CVs range from <1% for density measures to 4% for microarchitecture parameters in our laboratory.[22]

Total and trabecular volumetric BMD (Tt.BMD, Tb.BMD; mg HA/cm^3), trabecular number (Tb.N; 1/mm) and thickness (Tb.Th; mm) were obtained by the standard morphologic analysis[20] as described in detail elsewhere.[19]

Bone size and cortical parameters, including total cross-sectional area (Tt.Ar; mm^2), cortical volumetric BMD (Ct.BMD; mg HA/cm^3), cortical thickness (Ct.Th; mm), and cortical porosity (Ct.Po; %) were determined using an automated segmentation method.[23,24]

2.4.3. Finite element analysis (FEA)

Estimates of bone strength were based on custom FEA software (FAIM, Version 6.0; Numerics88 Solutions, Calgary, Canada) applied to each HR-pQCT scan using a linear, homogenous model. A uniaxial compression test was simulated on each radius and tibia using a 1% axial strain, Young's modulus of 6829 MPa and a Poisson's ratio of 0.3.[25] Our primary estimate of bone strength was failure load (N) based on 2% of the elements exceeding 7000 microstrain.[26]