Journal of Clinical Densitometry: Assessment & Management of Musculoskeletal Health, vol. ■, no. ■, 1–5, 2015

1094-6950/■:1–5/$36.00
http://dx.doi.org/10.1016/j.jocd.2015.02.005

Original Article

Bilateral Asymmetry of Radius and Tibia Bone Macroarchitecture and Microarchitecture: A High-Resolution Peripheral Quantitative Computed Tomography Study

Erin M. Hildebrandt,[1,2] *Sarah L. Manske,*[1,2] *David A. Hanley,*[1,2] *and Steven K. Boyd*[*,1,2]

[1]*Department of Radiology, Cumming School of Medicine, University of Calgary, Calgary, Canada; and* [2]*McCaig Institute for Bone and Joint Health, University of Calgary, Calgary, Canada*

Abstract

Studies assessing bone health often select the dominant or nondominant limb to scan, but not both, for efficiency reasons. New scanning technology allows 3-dimensional (3D) visualization of the microarchitecture in bone, but it is not well understood whether there are differences between the dominant and nondominant limbs. Using 3D high-resolution peripheral quantitative computed tomography (HR-pQCT), the aim of this study is to investigate the effect of limb dominance on bone macroarchitecture and microarchitecture. Healthy male and female participants (N = 100; 59 female, 41 male), mean age 30.7 ± 12.1 years, were scanned at both radii and tibiae using HR-pQCT. Hand and foot dominance were determined by the participant's self-report. Most participants were right hand dominant (94.0%) and right foot dominant (91.0%). In the pooled cohort, the dominant radius had significantly greater cortical area (2.11%; $p = 0.002$) and failure load (3.00%; $p = 0.001$). At the tibia, the dominant foot had significantly lower bone mineral density (−0.77%; $p = 0.042$), cortical area (−1.05%; $p = 0.031$), and thickness (−1.51%; $p = 0.017$). For females, there were no differences at the radius, but at the tibia, the dominant side had greater cross-sectional area (1.03%; $p = 0.044$). Our data suggest that dominance has a small yet significant effect on macroarchitecture at both the ultradistal radius and tibia but not microarchitecture. This work emphasizes that it is important to be consistent in the selection of either dominant or nondominant limbs for HR-pQCT cohort studies; however, in the case where the opposite limb needs to be scanned, there would be small differences in macroarchitecture and no significant differences in microarchitecture anticipated.

Key Words: Bilateral asymmetry; bone microarchitecture; bone mineral density; dominance; high-resolution peripheral quantitative computed tomography.

Introduction

Asymmetry is well established in human long bones. Specifically, right side upper limb long bones have been shown to be longer and wider, regardless of hand-dominance, which is presumably a result of a predominance of right-handed individuals and increased mechanical loading *(1)*. Bones are dynamic structures that respond to mechanical stimulation at both the macroarchitectural and microarchitectural level *(2)*, and this is most apparent in athletic populations because of increased loading patterns on dominant upper limbs. In racquet sport players, for example, the dominant forearm has significantly greater bone mineral density (BMD), bone mineral content (BMC), and cross-sectional bone area (BA) when compared with the nondominant arm *(3,4)*.

Clinical studies assessing bone quality at peripheral sites, such as the distal radius, generally select either the dominant or the nondominant limb to scan. Others have shown in the general population using dual-energy X-ray absorptiometry

Received 11/20/14; Revised 02/07/15; Accepted 02/11/15.
*Address correspondence to: Steven K Boyd, PhD, McCaig Institute for Bone and Joint Health, University of Calgary, Room HRIC 3AC64, 3280 Hospital Drive NW, Calgary, Alberta, Canada T2N 4Z6. E-mail: skboyd@ucalgary.ca

(DXA) that BMC and BA are greater at the dominant distal forearm, whereas there are no differences in areal BMD (aBMD) between sides (5–7). Three-dimensional (3D) images from peripheral quantitative computed tomography (pQCT) allow assessment of volumetric BMD and differences in cortical and trabecular bone compartments. There are limited pQCT studies with mixed results assessing side-to-side differences at the radius, with some studies reporting no difference and others finding significantly greater cortical area, and total and cortical BMC and BMD at the dominant radius (8–11). Lower limb bones are also significantly different between dominant and nondominant sides, yet the effects are opposite to the upper limb (6,9). Studies have found that the nondominant leg has significantly greater BMD and aBMD when compared with the dominant leg (6,9). This is postulated to be from the inverse relationship between hand skill and lower leg motor neuron excitability, in addition to biomechanically loading the nondominant leg while performing tasks such as kicking (6,12).

The ability to measure in vivo human bone microarchitecture is relatively new using multislice 3D high-resolution pQCT (HR-pQCT). HR-pQCT is increasingly being used to assess bone microarchitecture in clinical research studies because it provides fine detail of both cortical and trabecular bone at the peripheral sites of the ultradistal radius and tibia. In the interest of efficiency, usually only one upper extremity and 1 lower extremity measurement are assessed per subject, typically on the nondominant limb. In cases where previous fractures have occurred, the opposite limb is selected for scanning to avoid artifacts. The importance of selecting a dominant or nondominant limb for HR-pQCT studies is not clear because little is known about differences in bone microarchitecture. Therefore, the purpose of this study is to compare bone macroarchitecture and microarchitecture between dominant and nondominant distal radius and tibia as measured using HR-pQCT.

Materials and Methods

Subjects

A total of 100 healthy participants (59 female and 41 male) were recruited from Calgary, Alberta, and surrounding area over a period of 8 years. Participant mean age was 30.7 ± 12.1 years with a minimum age of 16.6 years and maximum of 72.8 years, and reflects the age range of our ongoing study cohorts. Participant self-report determined hand and foot dominance by asking, ‘‘What hand do you write with?’’ and ‘‘What foot do you kick with?’’ Basic information about participant’s medical history was collected at scan time, including self-reported previous fracture locations and severity. Approval for all procedures was obtained from the Conjoint Health Research Ethics Board at the University of Calgary. All participants aged >18 years provided written informed consent before involvement in the study. For those participants aged <18 years, a parent provided written informed consent on behalf of their child.

High-Resolution Peripheral Quantitative Computed Tomography

Participants were scanned at both ultradistal radii and tibiae by HR-pQCT (XtremeCT; Scanco Medical, Brüttisellen, Switzerland) using the standard human in vivo scanning protocol (60 kVp, 1000 μA, 100 ms integration time) (13). Limbs were supported in the scanner using an anatomic brace provided by the manufacturer to immobilize the joint. Using the 2D scout scan, reference lines were placed manually at the midinclination tuberosity at the radius and at the plateau of the tibial end plate at the tibia (13). The first slice of the scan was acquired 9.5-mm (radius) and 22.5-mm (tibia) proximal from the reference line, the standard patient scan locations. Each scan produced a 9.02-mm scan length with 110 slices and a nominal isotropic resolution of 82 μm.

Because the scans were acquired over a number of years, more than one trained technician performed the scans; however, the same technician performed all 4 scans for each participant. Technicians also monitored the scans for motion artifact (e.g., blurring or discontinuities), and if there was a significant artifact, a second scan was performed. Scans were graded for motion artifact before analysis, with a score of 1 indicating no motion artifact and a score of 5 indicating severe motion artifact. For this analysis, any participant with a motion artifact ≥4 was removed (14). Images acquired were analyzed by trained technicians using the manufacturer’s standard method described in detail by others (15,16). From this standard morphologic analysis we obtained total BMD (Tt.BMD; mg HA/cm^3), trabecular BMD (Tb.BMD; mg HA/cm^3), and total area (Tt.Ar; mm^2). Trabecular number (Tb.N; mm^{-1}) was calculated based on the distance transformation method (17). Trabecular thickness (Tb.Th; mm) and area (Tb.Ar; mm^2) and were derived as described elsewhere (13). Cortical parameters were assessed including cortical area (Ct.Ar; mm^2), BMD (Ct.BMD; mg HA/cm^3), thickness (Ct.Th; mm), and porosity (Ct.Po; %) (18).

Finite-Element Modeling

Homogeneous finite-element meshes were generated from the 3D HR-pQCT image data, as has been described elsewhere (19). A uniaxial compression test using 1% axial strain was applied in the z direction on all radii and tibiae scans (19). A homogeneous tissue modulus of 6829 MPa and a Poisson ratio of 0.3 were also applied (19). Models were solved using a custom finite-element software (FAIM, version 6.0; Numerics88 Solutions, Calgary, Canada), and failure load (N) was calculated (20).

Statistical Analysis

To investigate the effect of dominance on bone macroarchitecture and microarchitecture, a 2-way mixed analysis of variance with factors of sex and limb dominance was performed. A subanalysis separating the right- and left-dominant cohort participants was performed to determine if any effects of dominance were associated with a specific limb. All analyses were performed using SPSS version 20.0 (IBM Inc; Chicago, IL). Significance was defined as $p < 0.05$.