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Reproducibility of Peripheral Quantitative Computed Tomography Measurements at the Radius and Tibia in Healthy Pre- and Postmenopausal Women

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Abstract

Purpose—The objectives of this study were to utilise the XCT-2000 pQCT scanner to determine the mean values and the reproducibility of in vivo total, trabecular, and cortical volumetric bone measurements at distal and diaphyseal sites of the radius and the tibia, as well as calf muscle and subcutaneous fat areas, in healthy pre- and postmenopausal women.

Methods—Twenty-nine women (14 premenopausal and 15 postmenopausal) were recruited to participate in this study. Distal and diaphyseal sites of the radius (at 4% and 20% of the length of the radius) and tibia (at 4%, 38%, and 66% of the length of the tibia) were examined.

Results—The root mean square coefficient of variation for measurements at the distal tibia gave the most favorable reproducibility values for total (1.5%) and trabecular (1.6%) density, whereas the diaphyseal tibia showed the most favorable reproducibility value for cortical density (0.3%). The root mean square coefficients of variation for measurements of muscle and fat cross-sectional areas at the calf were 0.6% and 0.7%, respectively. At the distal tibia, the mean values for total ($P < .05$) and trabecular ($P < .01$) density were significantly lower in postmenopausal women than in premenopausal women.

Conclusions—The data presented here indicate that XCT-2000 pQCT scans at the tibia provide highly reproducible measurements of total, cortical, and trabecular bone as well as muscle and fat cross-sectional areas. Furthermore, significant differences in volumetric bone measurements between healthy pre- and postmenopausal women were evident only at the distal tibia, suggesting that this site warrants further study.

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Keywords

Peripheral quantitative computed tomography (pQCT); Reproducibility; Radius and tibia; Cortical bone; Trabecular bone; Muscle area; Subcutaneous fat area; Postmenopausal women

The expression “bone quality” encompasses many diverse factors which may influence fracture risk [1]. In patients with osteoporosis, a loss of connectivity within trabecular bone, in conjunction with an increased porosity of cortical bone, reduces both the quantity and the quality of bone. A peripheral quantitative computed tomography (pQCT) scanner is a device that measures volumetric bone mineral density (vBMD in mg/cm^3) and cross-sectional geometric properties of bone tissue at peripheral skeletal sites. pQCT was introduced more than 30 years ago for imaging of the radius, and there have been several modifications to the original design since that time [2]. In contrast to the commonly used technique of dual-energy x-ray absorptiometry (DXA), which is limited to measuring areal bone mineral density (aBMD in g/cm^2), pQCT not only provides volumetric density measurements but also differentiates between trabecular and cortical components of bone. This measurement technique offers a means to examine changes and redistributions of bone mineral and thus contributes unique information to assessments of the ultimate strength and quality of bone. Moreover, in addition to bone geometric properties, pQCT can also be used to assess the cross-sectional area of muscle. In order to keep the level of muscle strain on bone within an operational range, bone modelling and remodelling alters bone mass and architecture. Thus, measurements of muscle area provide important data regarding muscle-bone interactions and adaptations of muscle to changes in skeletal geometry.

Most often, pQCT has been applied to measurements at the radius, and reproducibility values for the radius have been assessed for many pQCT scanners. More recently, pQCT scanners have also been used for measurements at the tibia [3,4]. The XCT-2000 pQCT scanner was developed by Stratec Medizintechnik (Pforzheim, Germany), and the only in vivo precision studies of tibia measurements that have been conducted with an XCT-2000 device were at the distal tibia in young children [5] and in tibial shaft fractures of young adults [6]. Measurement precision is dependent on a number of factors, including the in vivo nature of the measurement, the population of interest, the device used, and operator technique. Therefore, an assessment of the reproducibility of the XCT-2000 device at the tibia adds valuable data to the area of study concerning pQCT imaging. Of further interest is the fact that the proximal femur, which is a common site of fracture in women with osteoporosis, has a mechanical-loading history similar to the tibia.

The objectives of this cross-sectional study were to assess the in vivo reproducibility of density, mass, area, and geometry measurements using the XCT-2000 pQCT scanner and to determine any significant differences in trabecular and cortical bone at the radius and tibia between pre- and post-menopausal women. In addition, an assessment of the in vivo reproducibility of the pQCT technique for muscle and subcutaneous fat determination at the mid calf was conducted.

Materials and Methods

Study Participants

Healthy women, older than 18 years of age, were recruited from staff, students, and outpatients at McMaster University Medical Center. The postmenopausal status of these women was determined by self-report; natural menopause was defined as the age at which menses ceased for a period of 12 months. A prior diagnosis of osteoporosis or other metabolic bone diseases served as exclusion criteria. Twenty-nine women were recruited for this study: 14 premenopausal and 15 postmenopausal. Fifteen women (7 premenopausal and 8 postmenopausal) participated in the upper-limb study, and 15 women (also 7 premenopausal and 8 postmenopausal) participated in the lower limb study. The medical history and lifestyle characteristics of all participants were obtained by response to a questionnaire. The study was approved by the Hamilton Health Sciences Research Ethics Board.

pQCT

pQCT measurements were taken at 2 different sites of the radius and 3 sites of the tibia using a Stratec XCT-2000 pQCT scanner. The device is a translate-rotate, small-bore computed tomography (CT) scanner that acquires a transaxial image. The x-ray source (58 kV, 180 μA) is collimated to produce a narrow fan beam with an effective width of 2.3 mm. The total effective radiation dose associated with each examination is less than 2 μSv. Images were acquired with an in-plane voxel dimension of 0.2 mm (0.008 mm^3). To ensure machine stability, the pQCT device was assessed daily based on a quality control phantom (Stratec Medizintechnik, Pforzheim, Germany), which includes soft tissue equivalent material.

Scanning Procedure

For each participant, the nondominant arm or leg was selected for measurement on the basis of whether the patient was right- or left-handed. Exceptions were made when the nondominant arm or leg had been fractured within the past 10 years. The subjects were seated on a stationary chair, adjusted to the appropriate height, and were offered the use of a foot stool and cushion to optimize comfort. For the radius scans, the length of the bone from the humeroradial joint cleft to the styloid process was measured. 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. A radial or tibial adjustable clamp was used to support the limb and to limit motion during the scans. Care was taken to ensure that the limb being scanned was well supported and centred appropriately in the imaging field.

The scanner was positioned on the distal radius or distal tibia, and a coronal computed radiograph (scout view) was carried out for the operator to manually locate a reference line on the distal end of either the radius or the tibia. The measurement sites were located proximal to this reference line by a distance corresponding to 4% (distal radius) and 20% (diaphyseal radius) of the forearm length, and 4% (distal tibia) and 38% (diaphyseal tibia) of the tibia length. For the measurement of muscle cross-sectional area, the site used was at 66% of the length of the tibia (muscle cross-sectional area), where the largest calf diameter

is typically located. For the muscle scans, the device was manually positioned and the scan was performed without a scout scan. The reproducibility for each site was determined by performing the measurements twice on each subject. The subjects were repositioned between the measurements, and a new scout view was performed for the second measurement. Each scan required approximately 90 seconds, with some variability depending on the cross-sectional size of the forearm or lower leg. The same operator acquired images of the radius or tibia for each subject.

Measurement Parameters

Image analysis and the selection of threshold values were performed by using the manufacturer's software, version 5.40 (Stratec Medizintechnik). The following parameters were determined at the selected bone sites: (1) the mass of mineralized tissue in the cross-section (bone mineral content in mg); (2) the size of the cross-sectional area of the bone (area in mm^2); and (3) volumetric bone mineral density (vBMD in mg/cm^3). Parameters included: total vBMD (TOT_DEN), trabecular vBMD (TRAB_DEN), cortical vBMD (CRT_DEN), total content (TOT_CNT), trabecular content (TRAB_CNT), cortical content (CRT_CNT), total cross-sectional area (TOT_A), trabecular cross-sectional area (TRAB_A), cortical cross-sectional area (CRT_A), cortical thickness (CRT_THK), endocortical circumference (ENDO_CIR), periosteal circumference (PERI_CIR), polar moment of inertia (PMI), polar moment of resistance (PMR), and polar stress strain index (SSI).

To define the outer boundary of the bone and to distinguish trabecular bone from cortical bone, the pQCT system uses a contour algorithm that detects the periosteal surface of the bone based on a threshold of 280 mg/cm^3. After detecting the outer bone contour, there is concentric peeling of the outer 55% of voxels until a central area that covers 45% of the total bone cross-sectional area remains. From this central area, TRAB_DEN is determined. The actual relative cross-sectional area of the trabecular compartment is considerably larger than 45%, however, the resolution of the pQCT system is not sufficient to trace the exact border between trabecular and cortical bone. Therefore, this geometric definition of trabecular bone includes some margin of safety to exclude cortical bone from the trabecular region of interest (ROI). In the cortical compartment, many voxels are only partially occupied by cortical bone. At a threshold of 710 mg/cm^3, the number of such voxels that are included in the analysis is equivalent to the number excluded. CRT_DEN was measured as the mass of the mineral above this threshold divided by the volume occupied, which allows the error due to the partial volume effect to be minimized. In this study, cortical bone parameters were only determined at the diaphyseal sites of the radius and tibia.

For the analysis of muscle cross-sectional area, the ROI was defined to include the entire matrix (skin, subcutaneous tissue, muscle, and bone). Within this ROI, the total area of the muscle was determined with the threshold set at 40 mg/cm^3, and the total bone was assessed at the threshold of 710 mg/cm^3. Next, the total area of skin and subcutaneous fat was identified by using a threshold of -100 mg/cm^3. Subsequently, the total bone area and total areas of skin and subcutaneous fat were deducted from the ROI to yield the total muscle area. No additional volume was removed from inside the muscle with this approach.

Data Analysis

Descriptive statistics, including the number of subjects (*n*), mean, standard deviation (SD), and standard error of the mean (SEM) values were calculated for each variable. The precision error for all measurements was calculated as root mean square coefficients of variation (*rms*CV) of duplicate measurements by using the method proposed by Gluer et al [7]. Tests for normality were conducted on all the data sets, and 2-sided *t* tests were used for intergroup comparisons. Pearson correlation coefficients were calculated to compare total density values at all sites. Differences were considered significant at $P < .05$.

Results

The anthropometric characteristics of the study subjects are provided in Table 1. The mean ± SD age of the premenopausal subjects was 28 ± 8 years and, for post-menopausal subjects, was 55 ± 8 years. There were no significant differences between the 2 populations with respect to height, mass, or body mass index.

Distal Radius and Tibia

The trabecular bone parameters were analysed at the distal sites, and cortical bone parameters were analysed at the proximal sites, in order to compare the reproducibility of measurements with the XCT-2000 pQCT scanner at the radius and tibia. As a consequence of insufficient spatial resolution at the bone edges (partial volume effect), cortical bone parameters can be underestimated at distal skeletal sites. The literature suggests 3 variant cutoff points for accurate cortical bone measurements, which indicate that this effect is greatest for cortices that are thinner than either 2.5 mm [8], 4 mm [9], or 1.2 mm [10]. With respect to the subjects in the present study, the mean ± SD cortical thickness was 0.71 ± 0.04 mm at the distal radius, 0.44 ± 0.04 mm at the distal tibia, 2.48 ± 0.7 mm at the diaphyseal radius, and 4.88 ± 0.1 mm at the diaphyseal tibia.

The pQCT variables for pre- and postmenopausal women at the distal radius and tibia, respectively, are listed in Tables 2 and 3. Also given in each table, if applicable, is the statistical significance of the difference between pre-and postmenopausal women. Mean values for TRAB_DEN and TOT_DEN at the distal radius were 201 mg/cm^3 and 365 mg/cm^3, respectively, in premenopausal women, and the results were similar in postmenopausal women, at 193 mg/cm^3 and 368 mg/cm^3, respectively. None of the variables were lower to a statistically significant degree in the radii of postmenopausal women. However, at the distal tibia, results for TRAB_DEN and TOT_DEN were significantly ($P < .01$ and $P < .05$, respectively) lower in postmenopausal women, at 203 mg/cm^3 and 267 mg/cm^3 respectively, compared to premenopausal women, with mean measurements of 241 mg/cm^3 and 317 mg/cm^3, respectively. The differences in TOT_A between the pre- and postmenopausal women at both the radius and tibia were not statistically significant.

At the distal radius, TRAB_DEN measurements had the best reproducibility (*rms*CV of 2.1%), whereas *rms*CV for TOT_DEN was higher, at 5.1%. For the mass and geometry parameters, the *rms*CVs were higher, with the exception of TOT_CNT (2.2%). At the distal

tibia, reproducibility was generally better than that observed at the distal radius. The *rms*CV for TRAB_DEN was 1.6% and for TOT_DEN was 1.5%.

Diaphyseal Radius and Tibia

The results for bone and geometric variables at the diaphyseal sites of the radius and tibia, respectively, are presented in Tables 4 and 5. Mean values for CRT_DEN at the diaphyseal radius in pre- and postmenopausal women were 1253 mg/cm^3 and 1266 mg/cm^3, respectively, and, at the diaphyseal tibia, these data were very similar, at 1205 mg/cm^3 and 1204 mg/cm^3, respectively. There were no statistically significant differences between pre- and post-menopausal women at the diaphyseal radius or tibia for any of the measured density or mass variables. Likewise, the PMI, PMR, and SSI, which take into account both density and geometry data derived from pQCT, were not significantly different at the diaphyseal radius or tibia between pre-and postmenopausal women.

For the measurements of both pre- and postmenopausal subjects combined, the *rms*CV for CRT_DEN at the diaphyseal radius site, where the cortex is thicker, was 0.5%. The other cortical bone parameters were almost as precise with CRT_CNT at 0.6% and CRT_A at 0.9%. At the diaphyseal tibia, the precision of the cortical measurements was similar to that at the radius, with *rms*CVof 0.3% for CRT_DEN, 0.5% for CRT_CNT, and 0.6% for CRT_A. When examining the correlations between the TOT_DEN values at all 4 measurement sites (Table 6), the correlation between TOT_DEN at the 4% radius and the 20% radius was the greatest, with a Pearson correlation coefficient of 0.64 (P =.01).

Muscle Cross-sectional Area

Positioning at the 66% site was occasionally difficult because of the size of the instrument leg aperture (14 cm diameter) in relation to the diameter of a subject's calf. One study patient was unable to be scanned at the 66% tibia site because of an inability to properly fit the leg into the scanning aperture. However, in this population, patient positioning difficulties were not experienced at the 38% tibia site. The results for muscle, fat, and bone variables in pre- and postmenopausal women assessed at the 66% tibia site are listed in Table 7. There were no statistically significant differences between pre- and postmenopausal women for these parameters at this site. The reproducibility for all parameters at the 66% tibia site was good, with total *rms*CV values between 0.6%–0.7%.

Discussion

The ability of pQCT measurements to record density, mass, area, and geometry changes in cortical and trabecular bone compartments may be useful for improving the detection of bone loss in clinical practice. Nevertheless, the diagnostic value of this technique depends upon the precision of the particular method, the bone site measured, and the device used. This study was conducted to determine the in vivo reproducibility of XCT-2000 pQCT measurements at the radius and tibia, and to assess significant differences between pre- and postmenopausal women.

This in vivo evaluation demonstrated that the XCT-2000 pQCT scanner provides efficient precision, not only for the upper limb bones for which it was primarily designed but also for

the tibia. The distal tibia had the most favorable reproducibility for TOT_DEN (1.5%) and TRAB_DEN (1.6%), whereas the diaphyseal tibia was the most reproducible site for CRT_DEN (0.3%), which may be a consequence of the fact that it is easier for patients to keep the tibia immobile during a scan. At the radius, small movements that may be imperceptible to patients can significantly affect precision. Furthermore, given the strong interrelationship between muscle force and bone strength, quantification of muscle area changes may also be valuable in the diagnosis of bone disorders. In this study, 1 patient could not complete the muscle area measurement at the 66% tibia site due to the limited size of the aperture. The *rms*CV values for muscle and subcutaneous fat areas at the 66% tibia were between 0.6%–0.7%. No significant differences were detected in muscle area between pre- and postmenopausal women.

Reported study results were coefficients of variation (CV) values for the XCT-900 and XCT-960 scanners of less than 3% for total BMD and less than 2% for trabecular BMD at the radius [11–16]. Boonen et al [17] measured in vivo precision at the distal radius by using the XCT-900 in 129 healthy female subjects who were aged 70–87 years [17]. In this population, the investigators reported CV precision errors of 2.4%, 1.9%, and 2.2% for total, trabecular, and cortical densities, respectively. With few exceptions, pQCT has been almost exclusively applied at the distal radius, and only recently have new pQCT scanners been developed for measuring the tibia and femur. The necessity of characterizing the precision error of this technique for the specific population of concern in any given study was demonstrated by Grampp et al [12]. They used the XCT-960 to measure radial pQCT reproducibility in healthy pre- and post-menopausal women and in subjects with osteoporosis. They found that the precision error was higher in the group with osteoporosis than the healthy subjects for TOT_DEN and TRAB_DEN [12]. Sievanen et al [3] used the most recent version of pQCT scanners (XCT 3000) to measure *rms*CV values at the distal radius in 19 volunteers (12 men and 7 women) and at the distal tibia in 36 volunteers (15 men, 21 women), and found values similar to those determined in the study presented here using the XCT-2000 scanner. Furthermore, MacNeil and Boyd [18] conducted an in vivo longitudinal reproducibility study in 15 male and 15 female subjects at the distal radius and tibia with a high-resolution pQCT device. The short- and long-term *rms*CV values for TOT_DEN and TRAB_DEN at the distal tibia in the male participants were less than 0.55% and for women these values were closer to 1%.

It is noteworthy that the mean value for TRAB_DEN of the weight-bearing distal tibia for all the subjects in the present study (221 mg/cm^3) was significantly greater ($P = .03$) than that of the non–weight-bearing distal radius (197 mg/cm^3). Also, the mean values for CRT_DEN of the diaphyseal radius and tibia were significantly different ($P < .001$). This is in contrast with a report [3] in which the mean TRAB_DEN at the radius and tibia were found to be 237 mg/cm^3 and 235 mg/cm^3, respectively. This may be because the study by Sievanen et al [3] included both men and women in the analysis of TRAB_DEN, whereas the present study involved women only. At the distal radius, none of the variables were significantly lower in postmenopausal women compared with premenopausal women. Intriguingly, at the distal tibia, TOT_DEN and TRAB_DEN were significantly lower in postmenopausal women. Similar results were observed in a larger study conducted by Boutroy et al [19], in which a high-resolution pQCT device was used. Boutroy et al [19] found that all parameters except

for TOT_A were significantly different between pre- and postmenopausal women at the distal tibia. Moreover, when using the Densiscan 1000 (ScancoMedical, Zurich, Switzerland) in a similar population, Tsurusaki et al [20] showed that the rate of diaphyseal tibial vBMD loss was significantly greater than radial vBMD loss in postmenopausal women. In an in situ study by Groll et al [21], the correlation between trabecular bone at the tibia and the femur was found to be higher than the correlation between the radius and the femur, when using an XCT-3000 pQCT scanner. Accordingly, for scanners that cannot measure femoral bone density, a closer prediction of femoral bone properties is available from tibia measurements than from radius measurements. The results of the present study suggest that, since the in vivo *rms*CV values of the XCT-2000 pQCT device were excellent, particularly at the tibial sites, bone mineral measurements at the distal tibia may be a useful tool in the evaluation of age-related bone loss.

When using pQCT imaging technology, close attention must be paid to potential sources of imprecision, including soft-tissue thickness, the amount of marrow fat, beam hardening, inconsistencies in the alignment of the target bones with respect to orientation of the tomographic slice, and subject comfort to minimize movement artifacts [12]. For this study, verification of correct subject positioning relied on visual inspection of limb alignment. This is susceptible to some variability, as small changes in the reference line could result in considerable differences in the measured parameters. At the distal sites of either the radius or the tibia, this is particularly a concern because cross-sectional geometry changes rapidly along the longitudinal axis of the given bone. However, when taking into account the potential for variability, the study results indicate good reproducibility of the measurements at these sites.

In summary, the present study demonstrated that XCT-2000 pQCT scans at the tibia provide reproducible measurements of total, cortical, and trabecular bone. Furthermore, significant differences between pre- and post-menopausal women were found only at the distal tibia; this further suggests that bone measurements at the tibia may be a useful tool in the evaluation of age-related bone loss. The present study underscores the importance of defining and quantifying bone quality parameters at various skeletal sites in the interest of fracture-risk prediction and the assessment of skeletal health.

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Table 1

Anthropometric data of the study participants (mean ± SD)

Variable	Premenopausal subjects (*n* = 14)	Postmenopausal subjects (*n* = 15)	All subjects (*n* = 29)
Age (y)	28 ± 8	55 ± 8	42 ± 16
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Mass (kg)	64.0 ± 11.6	68.7 ± 12.7	66.4 ± 12.2
Body mass index (kg/m^2)	22.6 ± 3.1	25.0 ± 5.2	23.8 ± 4.4

SD = standard deviation.

Table 2

Reproducibility of bone variables at the 4% distal radius (mean ± SEM)

Variable	Premenopausal subjects (*n* = 7)	Postmenopausal subjects (*n* = 8)	All subjects (*n* = 15)	*rms*CV (%)(*n* = 15)
Density (mg/cm^3)				
TOT_DEN	365 ± 11.6	368 ± 25.2	365 ± 14.1	5.1
TRAB_DEN	201 ± 9.5	193 ± 12.9	197 ± 7.9	2.1
Mass (mg)				
TOT_CNT	117 ± 5.0	105 ± 4.0	111 ± 3.4	2.2
TRAB_CNT	29 ± 1.8	25 ± 1.5	27 ± 1.2	6.7
Area (mm^2)				
TOT_A	321 ± 11.1	295 ± 18.5	308 ± 11.1	6.5

*rms*CV = root mean square coefficient of variation; SEM = standard error of the mean; TOT_A = total area; TOT_CNT = total content; TOT_DEN = total density; TRAB_CNT = trabecular content; TRAB_DEN = trabecular density.

Table 3

Reproducibility of bone variables at the 4% distal tibia (mean ± SEM)

Variable	Premenopausal subjects (*n* = 7)	Postmenopausal subjects (*n* = 8)	All subjects (*n* = 15)	*rms*CV (%)(*n* = 15)
Density (mg/cm^3)				
TOT_DEN	317 ± 10.3	267 ± 12.6 *	290 ± 10.4	1.5
TRAB_DEN	241 ± 8.3	203 ± 7.6 **	221 ± 7.4	1.6
Mass (mg)				
TOT_CNT	317 ± 20.0	273 ± 16.6	294 ± 13.8	1.6
TRAB_CNT	109 ± 7.0	94.0 ± 5.7	101 ± 4.7	4.3
Area (mm^2)				
TOT_A	1001 ± 54.0	1024 ± 42.5	1013 ± 32.7	2.8

*rms*CV = root mean square coefficient of variation; SEM = standard error of the mean; TOT_A = total area; TOT_CNT = total content; TOT_DEN = total density; TRAB_CNT = trabecular content; TRAB_DEN = trabecular density.

* $P < .05$ for 2-sample *t* test.

** $P < .01$ for 2-sample *t* test.

Table 4

Reproducibility of bone variables at the 20% diaphyseal radius (mean ± SEM)

Variable	Premenopausal subjects (*n* = 7)	Postmenopausal subjects (*n* = 8)	All subjects (*n* = 15)	*rms*CV (%)(*n* = 15)
Density (mg/cm^3)				
TOT_DEN	890 ± 24.5	916 ± 34.9	899 ± 22.6	3.3
CRT_DEN	1253 ± 6.8	1266 ± 10.4	1259 ± 6.7	0.5
Mass (mg)				
TOT_CNT	97 ± 4.2	94 ± 2.3	95 ± 2.3	1.4
CRT_CNT	91 ± 4.1	88 ± 2.3	89 ± 2.2	0.6
Area (mm^2)				
TOT_A	110 ± 6.1	103 ± 4.4	107 ± 3.8	3.8
CRT_A	73 ± 3.5	70 ± 1.7	71 ± 1.8	0.9
Geometry				
CRT_THK (mm)	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.7	3.1
PERI_CIR (mm)	37 ± 1.0	36 ± 0.8	37 ± 0.7	5.5
ENDO_CIR (mm)	22 ± 1.0	20 ± 1.3	21 ± 0.9	1.9
PMI (mm^3)	1698 ± 189	1494 ± 91	1593 ± 101	2.1
PMR (mm^3)	229 ± 16	198 ± 7	213 ± 9	2.0
SSI (mm^3)	138 ± 16	208 ± 7	222 ± 9	1.7

CRT_A = cortical area; CRT_CNT = cortical content; CRT_DEN = cortical density; CRT_THK = cortical thickness; ENDO_CIR = endosteal circumference; PERI_CIR = periosteal circumference; PMI = polar moment of inertia; PMR = polar moment of resistance; *rms*CV = root mean square coefficient of variation; SEM = standard error of the mean; SSI = stress-strain index; TOT_A = total area; TOT_CNT = total content; TOT_DEN = total density.

Table 5

Reproducibility of bone variables at the 38% diaphyseal tibia (mean ± SEM)

Variable	Premenopausal subjects (*n* = 7)	Postmenopausal subjects (*n* = 8)	All subjects (*n* = 15)	*rms*CV (%)(*n* = 15)
Density (mg/cm^3)				
TOT_DEN	896 ± 15.1	884 ± 21.3	882 ± 17.1	5.7
CRT_DEN	1205 ± 8.4	1204 ± 12.2	1205 ± 7.4	0.3
Mass (mg)				
TOT_CNT	341 ± 21.3	309 ± 11.9	324 ± 12.2	1.3
CRT_CNT	324 ± 19.9	295 ± 10.4	308 ± 11.1	0.5
Area (mm^2)				
TOT_A	381 ± 22.7	353 ± 17.6	369 ± 14.4	4.9
CRT_A	269 ± 17.5	245 ± 9.3	256 ± 9.7	0.6
Geometry				
CRT_THK (mm)	5.0 ± 0.2	4.8 ± 0.1	4.9 ± 0.1	4.6
PERI_CIR (mm)	69 ± 2.0	66 ± 1.7	68 ± 1.3	2.5
ENDO_CIR (mm)	37 ± 1.3	36 ± 2.0	37 ± 1.4	7.5
PMI (mm^3)	22,480 ± 3265	18,120 ± 1539	20,146 ± 1763	1.1
PMR (mm^3)	1486 ± 149	1308 ± 86	1391 ± 84	1.1
SSI (mm^3)	1479 ± 145	1310 ± 83	1389 ± 81	1.2

CRT_A = cortical area; CRT_CNT = cortical content; CRT_DEN = cortical density; CRT_THK = cortical thickness; ENDO_CIR = endosteal circumference; PERI_CIR = periosteal circumference; PMI = polar moment of inertia; PMR = polar moment of resistance; *rms*CV = root mean square coefficient of variation; SEM = standard error of the mean; SSI = stress-strain index; TOT_A = total area; TOT_CNT = total content; TOT_DEN = total density.

Table 6

Pearson correlation coefficients and *P* values for TOT_DEN

TOT_DEN	4% radius	4% tibia	20% radius
4% tibia	−0.19; *P* = .49		
20% radius	0.64; *P* = .01 *	−0.23; *P* = .41	
38% tibia	0.15; *P* = .59	0.42; *P* = .12	0.34; *P* = .21

TOT_DEN = total density.

* Significant at *P* < .05.

Table 7

Reproducibility of cross-sectional muscle, subcutaneous fat, and bone area at the 66% tibia (mean ± SEM)

Area (mm^2)	Premenopausal subjects (n = 6)	Postmenopausal subjects (n = 8)	All subjects (n = 14)	*rms*CV (%)(n = 14)
Total muscle	5680 ± 228	5904 ± 208	5808 ± 151	0.6
Total fat	4523 ± 440	4730 ± 195	4641 ± 211	0.7
Total bone[a]	332 ± 18.1	315 ± 15.5	323 ± 11.5	0.7

*rms*CV = root mean square coefficient of variation; SEM = standard error of the mean.

[a]Includes total tibia and fibula.