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Differences in Tibia Morphology between the Sound and Affected Sides in Ankle Foot Orthosis using Survivors of Stroke

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Abstract

Objective—To examine differences between the affected and sound limbs in ankle-foot orthosis (AFO)-using survivors of stroke. AFOs and gait aids are commonly used to allow survivors of stroke to ambulate. Previous investigations of bone mineral density (BMD) in stroke survivors cite gait aid use, but have not controlled for their use when presenting outcomes.

Design—Observational study.

Setting—University of Oklahoma Bone Density laboratory.

Participants—Nine ambulatory, AFO-using survivors of stroke (ages 55-74 years, 13.5±4.4 years post-stroke, 6.5±1.4 years of AFO use).

Interventions—Not applicable.

Main Outcome Measures—Total body and hip areal BMD (aBMD) and bone mineral content (BMC) were assessed by DXA. The 4%, 38% and 66% sites of both tibiae were measured with peripheral Quantitative Computed Tomography (pQCT) for total, cortical and trabecular volumetric BMD (vBMD) and BMC. Bone geometry, bone strength index (BSI), strength strain index (SSI) and moments of inertia (I_{min} , I_{max}) were determined.

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This study was performed at the University of Oklahoma, Department of Health and Exercise Science in the Bone Density Research laboratory.

No data from this study has been publicly presented.

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Results—Total hip and trochanter BMC and aBMD were 7%-19% greater on the sound side ($p<0.05$). Total BMC and vBMD were 2%-21% ($p<0.05$) on the sound limb, depending on site. Trabecular BMC and vBMD and BSI values were 19%, 21%, and 31% higher ($p<0.05$) on sound limb at the 4% site. Cortical BMC and vBMD ($p<0.05$), and cortical thickness ($p<0.01$) were greater on the sound side at the 38% and 66% sites. Cortical area and bone strength (SSI, Imin) were greater ($p<0.05$) at the 66% site. Endosteal circumferences were greater on the affected side ($p<0.01$).

Conclusion—Interlimb differences in bone characteristics following a stroke persist despite returning to ambulatory status with AFO use.

Keywords

tibia; stroke; orthosis; osteoporosis

Strokes are known to be major and often debilitating events for the individuals that survive. Survivors may be wheelchair bound initially and some are bed-ridden by the event for months [1]. After inpatient rehabilitation and regaining ambulatory status, the return to the home environment can still lead to falls in about one in five survivors [2]. Instability while standing or walking have been shown to persist over the first year after the stroke [2]. Survivors of stroke have been studied to quantify changes in bone mineral density (BMD) and bone mineral content (BMC) of upper and lower limbs and the spinal column [3,4]. It is known that, in healthy individuals, bone will eventually recover mineral content following prolonged bed rest [5]. However, the effects of gait aid use to regain ambulatory status have not been differentiated from the effects of initial bed-rest followed by rehabilitation [6-8]. Previous work has established that the affected side (contralateral to the hemisphere of the brain in which the stroke occurred) suffers greater and more rapid deficits in BMC and BMD than the sound side (ipsilateral to the stroke) [9]. Studies on chronic (greater than 1 year post-stroke) survivors of stroke provide evidence that the differences between the limbs persist after the period of recovery (18-24 months post-stroke) and have been based on areal BMD (aBMD) changes or have focused on morphology and strength changes in the upper limbs [3,4,6,7,9].

Current knowledge of interlimb differences in lower limb bone quality after stroke is confounded by the ambulatory status of participants and therefore the mechanical loading environment of the measurement site(s) [3,4,6-9]. Most survivors of stroke return to walking with gait aids in about two to three months, though the time to walking has been shown to be inversely linked with the amount of body weight that they can tolerate placing on the affected side [6]. This shift in weight bearing may complicate rehabilitation progression and limit bone formation on the affected side. Even when limiting the sample to ambulatory survivors of stroke, many studies only report the number of individuals that utilized a gait aid [6,8]. They group all gait aids, from canes and walkers to orthotic devices, and rarely delineate what type of aids are used or how each device may change the loading scheme of the affected and sound sides.

A common residual deficit from a stroke is dropfoot from the loss of central control of the tibialis anterior muscle on the affected side. An orthotic device, known as an ankle-foot

orthosis (AFO) or ankle brace can be used to lift the toes during the swing phase of gait to assist in clearing the affected leg during limb advancement. The AFO can also provide coronal plane support to the ankle during affected leg's stance phase to assist in balance while advancing the sound leg. There is a gap in the literature regarding any effects that this change or shift in loading may have on the strength and morphology of the tibia of the affected leg.

Accordingly, the purpose of this study was to quantify interlimb differences in tibial morphology and strength between the affected and sound legs of survivors of stroke at utilize an AFO for assistance in ambulation. The affected and sound hips were also examined for interlimb differences in areal BMD and BMC.

Methods

A chart review of individuals that were fit with an AFO 6 months to 5 years (oldest electronic record) previous to data collection was conducted at the Oklahoma City, OK metropolitan area Hanger Clinic patient care centers. Potential participants were contacted about interest in the study and to clarify their diagnosis if it was missing from the electronic record. Individuals were considered for participation if they: had survived a stroke; were male or post menopausal female; were aged 55 to 75 years; had used an AFO (unilaterally) for ambulation and activities of daily living (ADLs) for at least 6 months; were at least 2 years post-stroke. Study participants were excluded by the following criteria: weight greater than 300 pounds; unilateral amputation of a lower limb (no control side); non-ambulatory status (unable or per medical advice); AFO use prior to the stroke. Once the initial criteria were met, potential participants were medically cleared to participate by their primary physician prior to visiting the testing laboratory. Study participants filled out a general health-status questionnaire, Barthel Index, and signed informed consent. Women also filled out a menstrual history questionnaire. This study was approved by the University of Oklahoma Health Science Center IRB.

Dual Energy X-ray Absorptiometry (DXA)

Study participants received total body and dual proximal femur (total hip, femoral neck, trochanter) DXA^a scans to assess areal BMD and BMC. The speed of the total body scan was set to the level appropriate for the study participant based on their anterior-posterior dimension at the level of the umbilicus. Standard speed was used on individuals that were up to 25 cm at the umbilicus; thick speed was used for individuals that were greater than 25 cm. All hip scans were performed on the detail setting. Scans were analyzed using the Encore 2010 software^a. The prevalence of osteopenia and osteoporosis in the hips was determined from the WHO criterion for the T-scores of each hip and derived from the aBMD values [6]. The coefficients of variation (CV%) for the DXA total body and hip scans ranged from 0.41 to 0.84, with least significant changes (LSCs) of 0.012 to 0.024 g/cm².

Peripheral Quantitative Computed Tomography (pQCT)

Study participants had each tibia scanned by pQCT^b at 4%, 38% and 66% of the tibia length from the distal end of the tibia. The total length of the tibia was defined as the distance from

the medial tibial plateau to the apex of the medial malleolus. The 4% site was used for total and trabecular bone mineral content (BMC), volumetric bone mineral density (vBMD), and areas. The bone strength index (BSI) for this site was computed as Total Area*Total vBMD². The 38% and 66% sites were used to assess total and cortical BMC, vBMD, and areas. Strength strain index (SSI) and the area moments of inertia (Imax and Imin) were calculated for the 38% and 66% sites. Periosteal (Peri_C) and endosteal circumferences (Endo_C) and cortical thickness (CTh) were also determined [10]. Imax and Imin were determined by first calculating the angle between the perpendicular axes and the maximal and minimal axes with the following equation:

$$\alpha = \frac{\tan^{-1} \left(\frac{2I_{xy}}{I_x - I_y} \right)}{2},$$

where I_x , I_y , and I_{xy} are the moments of inertia calculated by the Stratec software based on the perpendicular axes. The cross-sectional moments of inertia were calculated with respect to the rotated axes with the following equations:

$$\begin{aligned} I_{rotatedx} &= \frac{I_x + I_y}{2} + \frac{I_x - I_y}{2} * \cos(2\alpha) - I_{xy} \sin(2\alpha) \\ I_{rotatedy} &= \frac{I_x + I_y}{2} - \frac{I_x - I_y}{2} * \cos(2\alpha) + I_{xy} \sin(2\alpha) \end{aligned}$$

The greater value of $I_{rotatedx}$ and $I_{rotatedy}$ was set as I_{max} ; the lesser as I_{min} [10]. Coefficients of variation (CV%) for precision of total bone variables range from 0.21-1.28%. CV% for cortical bone variables range from 0.21-0.58%, and 0.36-1.56% for trabecular bone variables.

Statistics

Data are reported as mean $\pm$ standard error of the mean (SE). All testing results were entered into SPSS v18^c for statistical analysis. Paired t-tests were used to compare the affected leg data to the sound leg. A Chi-squared test was used to compare the presence of osteopenia and osteoporosis between the affected and sound limbs. Significance was set at $p < 0.05$.

Results

The nine participants in this study were 64.2 ± 1.9 years old, 172.7 ± 3.2 cm tall and weighed 85.1 ± 7.1 kg. They were 13.5 ± 4.4 years post-stroke and reported using an AFO for 6.5 ± 1.4 years. The average, self-reported lapse of time from the stroke to returning to walking was 11.8 ± 5.7 weeks, range: 2-52 weeks. Study participants reported Barthel Index of 95 ± 2.2 ; range 80 (n=1) to 100 (n=4). No study participants self-reported walking more than 1 mile per day and 4 reported walking less than 1 block per day on the general health questionnaire. Four of the nine study participants walked with a step-to gait, leading with their sound leg and the remaining five utilized a step-over gait pattern. Information about the frequency and duration of physical therapy was not collected. Although the degree of spasticity was not quantified for each study participant, no study participant had trouble

donning their AFO after measurements nor was unable to remain still during the measurements.

The AFOs that were used by the study participants included solid-ankle designs (n=1), hinged-ankle designs (n=5), and dynamic dorsiflexion-assisting designs (n=3). Two study participants had off-the-shelf (prefabricated) AFOs: one was a hinged design and one was a dynamic design. The remaining seven were fabricated from a model of the study participant's limb, and defined as custom AFOs. None of the designs removed the ankle joint from weight bearing. Six of the study participants used their AFOs to control medial-lateral instability at the ankle, including the off-the-shelf, hinged-AFO user.

Total body BMC was 2.65 ± 0.12 kg, total body aBMD was 1.154 ± 0.028 g/cm², and total body T-score was -0.3 ± 0.4 (range -1.6 to 2.0). Total leg and proximal femur areal BMD and BMC results and the prevalence of osteopenia and osteoporosis are presented in Table 1. One study participant's DXA total hip and trochanter data had to be excluded after a software error occurred on the study participant's sound side hip scan and the data was not recoverable; the study participant's femoral neck data was unaffected by the error. The affected side had significantly ($p < 0.05$) lower aBMD and BMC values than the sound side for all variables except for the femoral neck BMC ($p = 0.19$). Total leg BMC was 16% lower on the affected side. Total hip and trochanter BMCs were 12% and 19% lower, respectively. Total hip, femoral neck and trochanter aBMD values were lower on the affected side by 10%, 7%, and 12%, respectively. No differences were found in the incidence of osteopenia or osteoporosis between the affected and sound hips, femoral necks or trochanters.

Table 2 details the data from pQCT analysis of the 4% site. Bone area values were not different between the affected and sound sides. Total vBMD and BMC were greater on the sound side by 19% and 21%, respectively. Further, trabecular BMC and density values were 22% and 20% higher on the sound side. The BSI was 31% greater on the sound side than the affected side.

Bone characteristics of the 38% tibia site are presented in Table 3. The sound side showed greater total (5.9%) and cortical (7.5%) BMC. The total (6.0%) and cortical (2.1%) vBMD were also greater on the sound side. Total bone and cortical area values at the 38% site were not significantly different between limbs. The ratio of total BMC between the 4% and 38% sites was 15.9% greater on the sound side ($p = 0.014$). No difference was found in periosteal circumference ($p = 0.71$). However, there was a significant difference in endosteal circumference ($p = 0.004$) with the affected side having 7.1% greater values. This finding was reflected by a significant limb difference in cortical thickness ($p = 0.003$), with the sound side being 8.0% greater. Estimates of bone strength were not significantly different ($p > 0.05$) between limbs. A trend for a difference was found in the SSI/BMC ratios at the 38% site ($p = 0.057$).

Bone characteristics of the 66% tibia site are presented in Table 4. For the total bone analysis, there was a significant difference in the vBMD and BMC, but not area. The total BMC was found to be 10.6% lower on the affected side. Total vBMD was 10.4% lower on the affected side. Analysis of the cortical bone found differences in the BMC and area, but

not vBMD. BMC was found to be 14.4% greater on the sound side, while area was 15.8% greater. Like the 38% site, there was no difference between the periosteal circumferences ($p>0.05$) but the affected side had a 6.4% greater value for the endosteal circumference ($p=0.002$), which partially explains the 16.0% lower value of the cortical thickness ($p=0.001$) for the affected side. The SSI of the 66% site was 10.3% greater on the sound side ($p=0.024$). No significant limb difference was found for $I_{\max}$. $I_{\min}$ was 30.6% lower on the affected side ($p=0.014$) and led to a 38.8% greater $I_{\max}/I_{\min}$ ratio on the affected side ($p=0.018$). There was no significant ($p>0.05$) difference in the SSI/BMC ratio at the 66% site. There was a trend for a difference between the BMC ratios of the 4% and 66% sites ($p=0.058$).

Discussion

The primary aim of this study was to observe interlimb differences in tibia morphology and strength specific to ambulatory, AFO-using survivors of stroke. We found profound losses in both trabecular and cortical bone mineral content relative to area that resulted in decreases in vBMD. Greater relative losses in trabecular bone were evident, based on larger interlimb differences in BMC at this site and the interlimb difference in the ratio of total BMC between the trabecular-rich and a cortical-rich site. Accordingly, interlimb differences in estimated strength were greatest in trabecular rich skeletal regions. Variations in interlimb differences between cortical-rich sites may be reflective of variations in stress and strain patterns along the tibia. Losses in bone strength at cortical-rich sites appear to be directly related to increased porosity, particularly at the endosteal surfaces.

The percentage losses for the affected side total hip, as measured by DXA, are similar to those previously reported over the first year post-stroke. The prevalence of total hip osteoporosis on both the sound and affected sides was similar to previous acute stroke studies [11]. The aBMD values in the current study were lower for both femoral necks than previously reported in other chronic survivor of stroke studies [12,13]. However, the percentage difference between the femoral neck aBMDs that was similar to differences previously reported [6,12].

Although the hip is a trabecular rich site, interlimb differences in total hip BMC and aBMD were more comparable to the total BMC and vBMD differences at the cortical rich 66% tibia site than at the trabecular rich 4% tibia site. However, interlimb differences in total hip BMC and aBMD were greater than that of the 38% site. Since the total hip scan includes cortical and trabecular bone, the difference might be expected to fall between the tibia trabecular site and cortical site differences. Differences in the femoral neck aBMD were similar to the difference in total vBMD found at the 38% tibia site and less than the 4% and 66% total vBMD differences. This is a curious result as the femoral neck sees a greater proportion of its loading as bending, not as direct compression like the 38% site. The 38% site is also predominantly cortical bone, not trabecular bone like the femoral neck. Percentage difference between the trochanters' BMC was closer to the percentage difference at the total 4% BMC than at the diaphyseal sites, although the trochanter aBMD difference was far less than the total and trabecular vBMD difference at the 4% site and nearer to the total 66% vBMD difference. The comparison of interlimb differences in BMD between central and

peripheral measurement sites is complicated by the fact that pQCT provides a 3-dimensional measure, whereas DXA provides a 2-dimensional measure and does not separate cortical and trabecular bone tissue. Still, the discrepancy between the hip and 4% tibia differences may lend further support to shielding mechanism by the AFO for the distal tibia, and may also indicate that sufficient loading of the bone is seen at the hip and mid to proximal tibia to maintain mineral content in the affected limb.

The greatest differences between the affected and the sound sides were seen at the 4% tibia site. This, and significant interlimb differences found in total BMC ratios between trabecular and cortical rich sites, indicates that the trabecular bone has been more affected by the changes in loading of the affected leg following the stroke. Two other studies have looked at the 4% site in survivors of stroke. This study shows considerably greater losses in total and trabecular BMC, vBMD and BSI than those previously reported [14,15]. There may be a functional difference between the group of study participants previously reported and the cohort of this study, as Pang *et al.* required that their study participants be able to achieve 60% age-adjusted maximum heart rate without cardiac symptoms and the current study did not, making Pang *et al.*'s cohort possibly less affected by their stroke [14,16]. Talla *et al.*'s cohort was similar to that of the present study: ambulatory, but not necessarily independent of gait aids, though the use of orthotics was not reported [15]. The greater losses seen in the AFO users, compared to possible non-users, may stem from shielding effects of the orthosis on the affected leg. Decreased activity levels in study participants requiring an AFO to ambulate could also lead to the greater differences seen in the present study.

At the 38% site, the decrease in cortical content and thickness on the affected side compared to the sound side was a result of the increased endocortical resorption without periosteal expansion. Interlimb differences in bone content did not translate to interlimb differences in bone strength for this site. The strength to mass ratio as calculated as the SSI/BMC ratio remained similar between limbs, suggesting that the bone maintained the necessary geometric arrangement needed to retain its strength. Our findings differ from those of Pang *et al.*, who found limb differences in strength (BSI/SSI) near this site (30%) [16]. This is likely due to difference in areas: while we found greater interlimb differences in cortical BMC and thickness than Pang *et al.*, they reported significant differences in area values which have large effects on bone strength [16,17]. The ratio of the BMCs of the 38% site to the 4% site was closer to that reported for spinal cord injury survivors (0.63) on the affected side and closer to normal (1.00) on the sound side [18].

Lower cortical content resulting from endosteal resorption on the affected leg at the 66% site translated to the differences seen between the bone strength measures of $I_{\min}$ and SSI. A direction specific loss, indicated by the change in $I_{\min}$ but not $I_{\max}$, and therefore, the $I_{\max}/I_{\min}$ ratio, may be indicative of direction-specific loading changes as a result of AFO use during periods of ambulation. The difference in SSI at the 66% site found in this study differs from the results of Talla *et al.*, who did not find a significant difference in the SSI [15]. This may further highlight the difference in the sample populations used, or could be related to the use of AFOs by the study participants of the present study. With the greater percentage differences between the affected and sound sides found in the present study, the former explanation is more likely.

Study Limitations

The cross-sectional design of this study limits the ability to determine the time course of bone content or strength changes after stroke in AFO users. This, and lack of a directly related control group limits the ability of this study to differentiate differences between the affected and sound sides that can be attributed to the use of an AFO independent of effects of the stroke. The use of a control group was considered, but dismissed based on the clinical presentation of the sample and the difficulty in finding a similar presentation (i.e. duration of mechanical unloading) in a non-clinical population. Our group and others have previously established that small, usually non-significant differences exist between the lower limbs of healthy controls that do not play a sport that requires a large loading imbalance (i.e. high jump or long jump) [19,20]. The interlimb differences found in the present study are considerably greater than the pQCT measurement error and interlimb differences found with normal side dominance.

Large effect sizes were expected based on previous cross-sectional unilateral unloading studies [3,9,11,14-16,19], reducing the sample size needed for sufficient power to detect interlimb differences. Still, the small sample size still limits the ability to generalize the results to other survivors of stroke and because of the exploratory nature of our study we had several outcome variables. However, our findings are directionally aligned, consistent, and complementary, strongly suggesting that our differences are real and not simply spurious findings that would be suggestive of type I error. Despite these study limitations, our findings suggest a potential interaction between the effects of stroke and AFO use on bone health may exist, providing a rationale for prospective studies.

Conclusions

This study confirms that differences between the sound and affected legs of survivors of stroke persist after the recovery period. Returning to ambulatory status with an AFO for ankle stability may not provide sufficient stimulus to rebuild bone lost during the initial bed rest and recovery periods or may shift the loading patterns of ground reaction forces to change how and where bone is deposited to retain sufficient strength for supporting the body. Further research is needed to determine if the use of an AFO attenuates bone losses through early mobilization or accelerates bone losses through a shielding mechanism. These studies will provide insight towards improving AFO designs to decrease any negative effects or further increase positive effects in conjunction with physical therapy.

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Abbreviations

aBMD	areal Bone Mineral Density
ADLs	Activities of Daily Living
AFO	Ankle Foot Orthosis
BMC	Bone Mineral Content
BMD	Bone Mineral Density
BSI	Bone Strength Index
CTh	Cortical Thickness
DXA	Dual-energy X-ray Absorptiometry
Endo_C	Endosteal circumference
Imin	Minimum rotated Moment of Inertia
I_{max}	Maximum rotated Moment of Inertia
Peri_C	periosteal circumference
pQCT	Peripheral Quantitative Computed Tomography
SSI	Strength-Strain Index
vBMD	volumetric Bone Mineral Density

Summary

This study examined differences in hip and tibial BMD and tibial bone strength in ambulatory survivors of CVA that use an ankle-foot orthosis. Regaining ambulatory status did not appear to improve differences between the limbs compared to other samples of survivors of CVA.

Table 1
Areal BMD and BMC and Prevalence of Osteopenia and Osteoporosis

Variable	Affected Limb	Sound Limb
Leg BMC*** (g)	465.56 ± 19.92	548.67 ± 29.97
Total Hip BMC* (g)	28.68 ± 1.42	31.90 ± 2.03
Total Hip aBMD* (g/cm ²)	0.849 ± 0.037	0.936 ± 0.049
Total Hip T-score*	-1.5 ± 0.3	-0.9 ± 0.4
%Osteopenia/%Osteoporosis	62.5%/12.5%	50%/0%
Femoral Neck BMC (g)	4.37 ± 0.16	4.54 ± 0.22
Femoral Neck aBMD* (g/cm ²)	0.832 ± 0.035	0.885 ± 0.037
Femoral Neck T-score*	-1.7 ± 0.3	-1.3 ± 0.3
%Osteopenia/%Osteoporosis	66.7%/22.2%	66.7%/0%
Trochanter BMC* (g)	9.08 ± 0.58	10.59 ± 0.93
Trochanter aBMD* (g/cm ²)	0.684 ± 0.025	0.759 ± 0.041
Trochanter T-score	-1.7 ± 0.3	-1.2 ± 0.3
%Osteopenia/%Osteoporosis	50%/25%	37.5%/12.5%

Data reported as mean ± SE.

* : p<0.05;

** : p<0.01;

*** : p<0.001.

BMC: bone mineral content; aBMD: areal bone mineral density.

Table 2

Bone characteristics at the 4% tibia.

Variable	Affected Limb	Sound Limb
Total BMC [*] (mg/mm)	237.12 ± 9.38	294.36 ± 21.90
Trab BMC [*] (mg/mm)	176.68 ± 9.58	222.71 ± 20.81
Total vBMD ^{**} (mg/cm ³)	225.28 ± 13.60	269.77 ± 14.31
Trab vBMD ^{**} (mg/cm ³)	191.96 ± 14.17	230.94 ± 16.13
Total Area (mm ²)	1068.2 ± 51.2	1095.86 ± 70.02
Trab Area (mm ²)	937.4 ± 48.7	963.29 ± 64.17
BSI [*] (mg ² /mm ⁴)	5.40e7 ± 4.95e6	8.08e7 ± 8.80e6

Data reported as mean ± SE.

* : p<0.05;

** : p<0.01;

*** : p<0.001.

BMC: bone mineral content; vBMD: volumetric bone mineral density; Trab: trabecular; BSI: bone strength index.

Table 3

Bone characteristics at the 38% tibia.

Variable	Affected Side	Sound Side
Total BMC [*] (mg/mm)	343.00 ± 15.70	361.99 ± 19.92
Cort BMC [*] (mg/mm)	322.95 ± 16.87	344.84 ± 19.59
Total vBMD ^{***} (mg/cm ³)	830.23 ± 25.03	880.34 ± 19.03
Cort vBMD [*] (mg/cm ³)	1143.72 ± 13.02	1164.68 ± 10.89
Total Area (mm ²)	415.3 ± 21.6	413.6 ± 27.0
Cort Area (mm ²)	280.8 ± 14.7	292.0 ± 15.5
Endosteal Circ ^{**} (mm)	40.81 ± 1.77	38.06 ± 1.74
Periosteal Circ (mm)	72.05 ± 1.86	71.80 ± 2.30
Cort Thickness ^{**} (mm)	4.97 ± 0.20	5.37 ± 0.17
SSI (mm ³)	1745.33 ± 114.67	1804.17 ± 158.41
I _{max} (mm ⁴)	16702.5 ± 1687.0	16958.4 ± 2022.3
I _{min} (mm ⁴)	10506.2 ± 1061.5	11666.3 ± 1703.7
I _{max} /I _{min}	1.607 ± 0.088	1.492 ± 0.072
SSI/BMC	5.061 ± 0.147	4.921 ± 0.176
Total BMC 4%/38% [*]	0.701 ± 0.036	0.812 ± 0.040

Data reported as mean ± SE.

* : p<0.05;

** : p<0.01;

*** : p<0.001.

BMC: bone mineral content; vBMD: volumetric bone mineral density; Cort: cortical; Circ: circumference; SSI: strength strain index; I_{max}: maximum moment of inertia; I_{min}: minimum moment of inertia.

Table 4

Bone characteristics at the 66% tibia.

Variable	Affected Side	Sound Side
Total BMC ^{**} (mg/mm)	246.16 ± 16.61	390.74 ± 22.46
Cort BMC ^{**} (mg/mm)	302.33 ± 18.46	348.74 ± 22.81
Total vBMD ^{***} (mg/cm ³)	593.68 ± 31.00	657.06 ± 30.32
Cort vBMD (mg/cm ³)	1105.83 ± 13.26	1113.04 ± 12.21
Total Area (mm ²)	598.4 ± 34.1	601.4 ± 40.0
Cort Area ^{**} (mm ²)	267.5 ± 16.9	313.4 ± 20.5
Endosteal Circ ^{**} (mm)	63.4 ± 3.0	59.5 ± 3.1
Periosteal Circ (mm)	86.4 ± 2.4	86.6 ± 2.8
Cort Thickness ^{***} (mm)	3.67 ± 0.23	4.30 ± 0.26
SSI [*] (mm ³)	2375.64 ± 158.24	2635.17 ± 233.56
I _{max} (mm ⁴)	29139.9 ± 3102.0	28221.7 ± 3003.3
I _{min} [*] (mm ⁴)	15214.0 ± 1424.0	21744.9 ± 3189.1
I _{max} /I _{min} [*]	1.927 ± 0.142	1.379 ± 0.098
SSI/BMC	6.791 ± 0.222	6.672 ± 0.273
Total BMC 4%/66%	0.691 ± 0.033	0.753 ± 0.035

Data reported as mean ± SE.

* : p<0.05;

** : p<0.01;

*** : p<0.001.

BMC: bone mineral content; vBMD: volumetric bone mineral density; Cort: cortical; Circ: circumference; SSI: strength strain index; I_{max}: maximum moment of inertia; I_{min}: minimum moment of inertia.