Lactation is associated with greater maternal bone size and bone strength later in life

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ABSTRACT

Purpose

Pregnancy and lactation have no permanent negative effect on maternal bone mineral density but may positively affect bone structure in the long-term. We hypothesized that long lactation promotes periosteal bone apposition and hence increasing maternal bone strength.

Methods

Body composition, bone area, bone mineral content, and areal bone mineral density of whole body and left proximal femur were assessed using DXA, and cross-sectional area and volumetric bone mineral density of the left tibia shaft were measured by pQCT in 145 women (mean age 48 years, range 36 – 60 years) 16 to 20 years after their last parturition. Hip (HSI) and tibia (TBSI) strength indexes (TBSI) were calculated. Medical history and lifestyle factors including breastfeeding patterns and durations were collected via a self-administered questionnaire. Weight change during each pregnancy was collected from personal maternity tracking records.

Results

Sixteen to twenty years after the last parturition, women who had breastfed in total more than 33 months in their life, regardless of the number of children, had greater bone strength estimates of the hip (HSI = 1.92 vs. 1.61) and the tibia (TBSI = 5507 vs. 4705) owing to their greater bone size than mothers who had breastfed less than 12 months ($p<0.05$ for all). The differences in bone strength estimates were independent of body height and weight, menopause status, use of hormone replacement therapy and present leisure time physical activity level.

Conclusions

Breastfeeding is beneficial to maternal bone strength in the long run.

Keywords: Lactation, bone strength index, bone size, breastfeeding, women

MINI ABSTRACT

The association between lactation and bone size and strength was studied in 145 women 16 to 20 years after their last parturition. Longer cumulative duration of lactation was associated with larger bone size and strength later in life.

INTRODUCTION

Maternal calcium and bone metabolism undergo significant adaptations to meet the calcium requirements for fetal skeletal growth and post-partum breast milk production (1). The mineral extraction from bone during pregnancy and lactation causes a transient decrease in bone mineral density (BMD) in mothers (2). However, maternal bone mass is regained after weaning (3). Therefore, this transient reduction of BMD does not necessarily affect maternal BMD in later years.

The evidence for the long-term effects of lactation on BMD is conflicting. Some studies reported higher BMD later in life with increased lactation (4-7), while others found lower BMD (8, 9) or no association (10-13). Nevertheless, a general view is that breastfeeding does not increase risk of fracture in later life (14-16). Conversely, parity and lactation is associated with reduced fracture risk, independently of changes in BMD (17, 18). These findings suggest that pregnancy and lactation do not compromise bone strength in the long run, and that it is not the change in BMD but probably the alterations in bone structural properties during lactation that are responsible for the reduction in risk of fracture.

The current study retrospectively examined the relationship between the duration of breastfeeding and bone properties in 145 women 16-20 years after their last parturition to assess the long-term effects of breastfeeding on estimates of bone strength.

SUBJECTS AND METHODS

Study design

This retrospective study was a part of the Calex-family study (“Effects of physical activity, vitamin D and calcium on musculoskeletal properties in three generations”) which was an extension study of the original Calex-study conducted in the city of Jyväskylä and its surroundings in Central Finland. The Calex-study subjects included 1367 girls who participated in the screening and were first contacted via class teachers teaching grades 4 to 6 (age 9 to 13 years old) in 61 schools in the city of Jyväskylä and its surroundings in Central Finland (96% of all the schools in these areas) in 1999-2001 (19). Of the eligible subjects, 396 girls participated in the laboratory tests one to eight times during a maximum period of 8 years. In the years 2003-4 and 2007-8, we invited the girls' other family members to participate in the Calex-family study (20, 21). Only the mothers from the later recruitment period are included in this present report. Due to the nature of the study design as a family study, no nulliparous women were included.

Medical history and lifestyle factors, including level of education, and current participation in leisure time physical activity (hours per week), information on breastfeeding durations, number of biological children, pre-pregnancy weight and height were collected via a self-administered questionnaire. Participants were also asked to provide detailed information on weight change during each pregnancy from their personal maternity tracking records which have been issued to mothers since the socialization of maternal healthcare in Finland. Current intakes of calcium and vitamin D were assessed from food records (22). Breastfeeding was expressed in total months of both exclusive (giving an infant no food or liquid other than breast milk) and partial (giving a baby some breast milk in addition to other liquid or solid foods) breastfeeding. Hence this represents the cumulative total duration of lactation experienced by the mother throughout her reproductive life.

Subjects

Two-hundred and twelve mothers (mean age 48 years, range 36 – 60 years) participated in the laboratory assessments. Of these, 206 women provided valid information on the number of biological children they had. Thirteen (6.8%) women reported having one child, 71 (37.2%) had two, 72 (37.7%) had three, 35 (18.3%) had four and 15 (7.5%) had more than four biological children. Participants who reported twin pregnancies (n = 5), or did not have pre-pregnancy anthropometric data (n = 56) were excluded. Finally, 145 mothers were included in this report.

The 145 participants were divided into quartiles according to the total months of breastfeeding they reported: 1) short-duration breastfeeding (SDB, n= 38, ≤ 12 months), medial-duration breastfeeding (MDB, n= 37, > 12 months but < 21 months), long-duration of breastfeeding (LDB, n= 36, ≥ 21 months but < 33 months), and very-long duration breastfeeding (VLDB, n= 34, ≥ 33 months). The study protocol was approved by the ethical committee of the Central Finland Health Care District. Written informed consent was given by all subjects prior to the assessments.

Anthropometrical- and body composition assessments

Body composition was assessed by dual-energy X-ray absorptiometry (DXA Prodigy; GE Lunar Corp., Madison, WI USA). The coefficient of variation (CV) of two repeated measurements on the same day was on average 0.7% for bone mass, 1.0% for lean mass, and 2.2% for fat mass in this study. Body weight and height were measured using standardized protocols and body mass index (BMI) was calculated as weight (kg)/height^2 (m^2).

Bone measurements

Bone area (BA, cm^2), bone mineral content (BMC, g), and areal bone mineral density (aBMD, g/cm^2) of the whole body (WB), left femoral neck (FN) and total femur (TF) were assessed by DXA. Hip strength index (HSI) was determined by the hip strength analysis (HSA) program, which has been described previously (23, 24). Briefly, the automated program measures aBMD and bone geometry within a narrow region corresponding to the cross-sectional area of femoral neck viewed in the DXA image. The regions of interest (ROIs) were located across the femoral neck at its narrowest cross-section and across the shaft 2 cm distal to the midpoint of the lesser trochanter. This method has been validated and has been shown as a significant predictor of hip fracture (25).

The left tibia was scanned using peripheral quantitative computerized tomography (XCT 2000; Stratec Medizintechnik, Pforzheim, Germany). The scan location was at 60% of lower leg length up from the lateral malleolus. The in-plane pixel size was 0.59mm x 0.59mm. Total bone cross-sectional area (CSA, mm^2), cortical CSA, total bone mineral content (BMC, mg/mm), cortical BMC and volumetric bone mineral density (vBMD, mg/cm^3), polar cross-sectional moment of inertia (CSMI, mm^4), periosteal circumference (mm) and endosteal circumference (mm) were determined using the Stratec software. The CV of two repeated measurements on the same subject on the same day was on average 1% for total CSA, cortical BMC and total BMC, and <1% for cortical vBMD. The tibia length (TL, cm) was measured from DXA scans (26, 27). TL was defined as the distance between the proximal edge of tibia (middle point of the line from medial to lateral condyle) and distal border of tibia (ankle joint surface). The CV of three repeated measurements of TL was 2.7%. Tibial bone strength index (TBSI) was calculated as the product of CSMI and cortical vBMD. This has been validated by its close correlation with the mechanically tested bending breaking force of bones (27, 28).

Statistical Analyses

All data were checked for normality using the Shapiro-Wilk's W-test in SPSS 15.0 for Windows. If data was not normally distributed, natural logarithm was used. Analysis of variance (ANOVA) with LSD post-hoc test was used to compare the differences in pre-pregnancy anthropometrics and age at each pregnancy between the breastfeeding groups as well as the differences in anthropometric, body composition, dietary energy and energy yielding nutrients, calcium and vitamin D intake, participation in leisure time physical activity and bone variables among groups 16-20 years after the last parturition. Chi-square test was used to compare the proportion of menopausal and non-menopausal and hormone replacement users and non-users. Correlation for parity, total and exclusive breastfeeding duration and bone strength estimates was assessed using Pearson´s correlation. Analysis of covariance (ANCOVA) was used to test whether the association between breastfeeding and bone strength indexes was independent of age, height, weight, menopause status, use of hormone replacement therapy, current leisure time physical activity level, and parity. Statistical significance was set at $p < 0.05$.

RESULTS

The characteristics of the participants in the year before the first pregnancy are shown in **Table 1**. No significant differences were found in age, height, weight or BMI between the groups before the first pregnancy. Gestational durations, weight gains, and average age at each consecutive pregnancy were also similar among all groups ($p > 0.05$ for all, Table 2).

Insert table 1 and 2 here

Sixteen to twenty years after the last parturition, no significant differences were observed among groups in age, height, weight, BMI, total fat, lean and bone mass, menopause status, use of hormone replacement therapy (HRT), current dietary energy and energy yielding nutrients, calcium and vitamin D intake as well as participation in current leisure time physical activity (all $p > 0.05$, **Table 3**).

Insert table 3 here

VLDB mothers had larger bone area of the total femur than SDB mothers ($p<0.05$), but no differences in BMC and aBMD (Table 4). The VLDB mothers also had greater tibial CSA, periosteal and endosteal circumference and CSMI but lower vBMD of the tibia than SDB mothers (all $p<0.05$). No differences were found in bone area, BMC and BMD of the whole body between the groups. The VLDB mothers had greater HSI and TBSI estimates than the SDB mothers ($p<0.01$, Figure 1 and 2). Parity correlated significantly with total breastfeeding and exclusive breastfeeding duration ($r=0.71$ and $r=0.36$, respectively; $p<0.001$ for both), but not with HSI ($r=0.08$, $p=0.338$) or

TBSI (r=0.05, p=0.539). Total duration of breastfeeding correlated significantly with HSI (r=0.27, p=0.001) and TBSI (r=0.17, p=0.043), while exclusive breastfeeding did not show a significant correlation with bone strength estimates. Analysis of co-variance showed that the association between breastfeeding and bone strength index estimates was independent of age, height, weight, parity, menopausal status, use of hormone replacement therapy and current leisure time physical activity level.

Insert Table 4 and Figures 1 and 2 here

DISCUSSION

In this study, we showed that mothers who had breastfed in total more than 33 months had significantly greater hip and tibia bone strength index estimates compared to the mothers who had breastfed less than 12 months. This difference was observed 16 to 20 years after the last parturition and was independent of age, height, weight, parity, menopausal status, use or hormone replacement therapy and current leisure time physical activity level.

The similar aBMD of the whole body and femoral and cortical vBMD of the tibia found among groups indicates that breastfeeding does not affect BMD in later life, which is in agreement with previous reports (1, 2). However, mothers who had breastfed in total more than 33 months had significantly lower vBMD of the whole tibia compared to the mothers who had breastfed less than 12 months, albeit that there was no difference in bone mass. Therefore, the greater hip and tibial bone strength index found in very long breastfeeding duration mothers is attributable to larger bone size, not higher BMD.

Reproduction is characterized by high bone turnover (29, 30) with a reduction of maternal BMD of around 5% during pregnancy (15). The weight gain during late pregnancy places an increased load upon the skeleton, requiring stronger bones. The bone loss and simultaneous need for bone strengthening against increased loads may be reconciled by an increase in bone diameter (31, 32), as for a given bone mass, the most economical way to increase the bending strength of a bone is to augment its outer dimension. It is well known that, mechanically, the spatial distribution of bone mass is more important than the amount of mass in determining the bone bending strength (33). The further the bone is distributed away from the neutral axis, the greater bending strength a bone has. Our data suggest that the additional mechanical demands placed on the skeleton were similar among the four groups because there was no difference in body weight before the first pregnancy and a similar pattern of gradual weight gain was observed in all groups in the subsequent pregnancies. Hence, the greater bone size found in very long breastfeeding mothers may not be ascribed to the increased mechanical load during pregnancy, but probably due to the lactation-associated estrogen deficiency.

Estrogen at high level promotes endocortical bone formation and inhibits periosteal formation (34-36), and this is considered to be one of the mechanisms underlying sexual dimorphism. Periosteal apposition is inversely associated with postmenopausal estrogen levels suggesting that periosteal apposition compensates for the decreased bone strength caused by the bone loss during menopause (37). The estrogen level is very low during lactation (38), which to some extent mimics the estrogen deficiency in postmenopausal women. Therefore, it is possible that the low levels of estrogen during lactation exert less inhibitory effects on periosteal bone formation thereby permitting periosteal expansion, leading to a bone with larger size at the end of lactation (39). Hence, this is a plausible mechanism to explain why the mothers who breastfed longer than 33 months had larger cross-sectional area of the tibia and femoral bone area compared to those who breastfed shorter duration. After weaning, the lost bone mass is regained, but the larger bone size built up during lactation persists, hence conferring greater bone strength later in life.

Our results appear to contradict a previous retrospective study which found that bone strength, **and higher bone volumes, were** associated with parity but not with lactation (40). However, this is partly explained by the fact that the earlier study used the average duration of lactation per infant in their analyses, whereas we used total cumulative duration of all lactation periods, a measure better reflecting the duration of low estrogen exposure. Hence, our data suggests that the permissive effects of lactation-associated estrogen deficiency play a more important role in promoting bone enlargement that does parity itself. **Also, a more recent prospective study showed decreases in hip cross-sectional area and bone mineral density during lactation (41). However, the relatively small number of subjects and wide variation in duration of lactation complicates interpretation of the results of this study.**

A limitation of the study was that neither nulliparous women, nor parous women who did not breastfeed, were included and hence our findings cannot be confirmed against control groups of women who have never been pregnant or never breastfed. Also, due to the retrospective nature of this study we were unable to obtain data for the changes of the hormonal milieu during and after pregnancy. A prospective study is needed to confirm our findings. In addition, we did not have pre-pregnancy data of bone traits from our subjects and therefore, it cannot be ruled out that the difference in bone strength and structure between mothers of different duration of breastfeeding already existed before first pregnancy. However, the similarity in body weight and height at pre-pregnancy suggest that the pre-pregnancy bone traits in those mothers may not differ significantly. In addition, the similar current physical activity level among groups indicates similar mechanical loading imposed to which the bone adapt its structural and material properties. Furthermore, breastfeeding data collected retrospectively, particularly after a considerable period of time, may be subject to recall bias. However, limited studies suggest that maternal recall does provide accurate estimates of initiation and duration of breastfeeding (42), with high validity even after 20 years (43).

In summary, longer duration of breastfeeding is associated with greater bone size and strength estimates in mothers later in life.

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DISCLOSURES

No disclosures.

FIGURE CAPTIONS

Fig. 1 Hip strength index (bars represent mean values and error lines indicate SD) of Finnish women in different breastfeeding groups. SDB = short duration of breastfeeding; MDB = medial duration of breastfeeding; LDB = long duration of breastfeeding; VLDB = very-long duration of breastfeeding.

Fig. 2 Tibia strength index (bars represent mean values and error lines indicate SD) of Finnish women in different breastfeeding groups. SDB = short duration of breastfeeding; MDB = medial duration of breastfeeding; LDB = long duration of breastfeeding; VLDB = very-long duration of breastfeeding.

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Table 1 Characteristics of Finnish women in different breastfeeding groups before their 1st pregnancy

Characteristic	SDB n=38	MDB n=37	LDB n=36	VLDB n=34
Age (years)	26.4 ± 4.5	25.5 ± 5.5	25.8 ± 3.0	25.0 ± 3.1
Height (cm)	164.6 ± 6.2	165.4 ± 6.3	166.2 ± 5.5	166.7 ± 5.8
Weight (kg)	57.6 ± 7.6	57.7 ± 8.5	57.4 ± 6.7	57.0 ± 5.8
BMI (kg/m^2)	21.3 ± 2.5	21.1 ± 3.0	20.8 ± 2.0	20.5 ± 1.4

Data are given as mean ± SD. BMI= body mass index; BF= Total breastfeeding months; SDB= short duration of breastfeeding; MDB= medial duration of breastfeeding; LDB= long duration of breastfeeding; VLDB= very-long duration of breastfeeding

Table 2. Characteristic of women in different breastfeeding groups in 3 consecutive pregnancies

Characteristic	Pregnancy	SDB n=38	MDB n=37	LDB n=36	VLDB n=34
Gestational durations (weeks)	1st	41 ± 2	41 ± 2	41 ± 1	41 ± 2
	2nd	41 ± 2	42 ± 2	41 ± 2	41 ± 2
	3rd	41 ± 2	42 ± 2	41 ± 2	42 ± 2
Age (years)	1st	26.4 ± 4.9	25.5 ± 5.5	25.8 ± 3.0	25.0 ± 3.1
	2nd	28.2 ± 3.5	30.2 ± 3.7	28.7 ± 3.4	27.4 ± 3.3
	3rd	30.6 ± 2.5	31.0 ± 4.3	31.7 ± 3.5	29.6 ± 3.4
Weight gain (kg)	1st	12.7 ± 4.1	12.1 ± 2.7	12.5 ± 3.1	11.6 ± 2.7
	2nd	11.6 ± 2.9	11.0 ± 2.5	12.1 ± 3.0	12.9 ± 2.6
	3rd	11.8 ± 3.8	9.6 ± 3.7	12.9 ± 2.9	13.3 ± 3.7

Data are given as mean ± SD. SDB= short duration of breastfeeding; MDB= medial duration of breastfeeding; LDB= long duration of breastfeeding; VLDB= very-long duration of breastfeeding.

Table 3. General characteristics of Finnish women in different breastfeeding groups 16-20 years after their last parturition

Characteristic	SDB	MDB	LDB	VLDB
	n=38	n=37	n=36	n=34
Age (years)	47.6 ± 5.0	49.2 ± 4.3	48.9 ± 4.9	48.2 ± 3.8
Height (cm)	164.2 ±6.2	165.0 ± 6.4	165.9 ± 5.7	166.4 ± 6.1
Weight (kg)	69.7 ± 14.9	68.1 ± 12.3	66.5 ± 10.9	66.3 ± 8.0
BMI (kg/m^2)	25.8 ± 5.2	25.1 ± 4.9	24.1 ± 3.3	24.0 ± 2.8
Total fat mass (kg)	26.0 ± 10.0	24.4 ± 9.9	23.8 ± 9.9	23.4 ± 8.5
Total lean mass (kg)	40.7 ± 5.1	40.5 ± 4.6	40.7 ± 4.1	41.6 ± 4.8
Total bone mass (kg)	2.6 ± 0.3	2.6 ± 0.4	2.6 ± 0.4	2.7 ± 0.5
Biological children	2.2 ±1.0‡	2.4 ± 0.7‡	3.0 ± 0.8‡	4.1 ± 1.9
Total BF months	7.6 ± 4.0‡	17.8 ± 2.2‡	27.9 ± 3.4‡	49.8 ± 17.9
Total exclusive BF months	5.1 ± 3.8‡	9.0 ± 5.8‡	13.1± 6.5†	19.7 ± 13.5
Postmenopausal	18%	16%	14%	9%
HRT	18%	8%	19%	15%
LTPA (hrs/week)	2.5 ± 1.9	2.6 ± 1.8	2.2 ± 1.5	2.6 ± 2.0
Diet Vitamin D (µg)	6.3 ± 3.3	6.6 ± 3.6	6.9 ± 3.5	5.5 ± 2.9
Diet Calcium (mg)	1170 ± 430	1170 ± 320	1190 ± 420	1160 ± 350

Data are given as mean ± SD. BMI= body mass index; BF= breastfeeding; Postmenopausal = % subjects who were postmenopausal; HRT = % subjects who were on hormone replacement therapy; LTPA= leisure time physical activity; SDB= short duration of breastfeeding; MDB= medial duration of breastfeeding; LDB= long duration of breastfeeding; VLDB= very-long duration of breastfeeding. † $p<0.01$; ‡ $p<0.001$ compared to VLDB mothers.

Table 4. Bone parameters of Finnish women in different breastfeeding groups 16-20 years after their last parturition

Variable	SDB	MDB	LDB	VLDB
	n=38	n=37	n=36	n=34
Whole body				
BA (cm^2)	2103 ± 188	2142 ± 213	2131 ± 222	2171 ± 212
BMC (g)	2523 ± 351	2563 ± 402	2566 ± 374	2656 ± 459
BMD (g/cm^2)	1.20 ± 0.1	1.19 ± 0.1	1.20 ± 0.1	1.21 ± 0.1
HIP				
BA_{FN} (mm^2)	4.78 ± 0.27	4.83 ± 0.35	4.79 ± 0.32	4.83 ± 0.26
BMC_{FN} (g)	4.66 ± 0.58	4.67 ± 0.66	4.68 ± 0.59	4.67 ± 0.67
$aBMD_{FN}$ (g/cm^2)	0.97 ± 0.11	0.96 ± 0.10	0.98 ± 0.11	0.96 ± 0.11
BA_{TF} (mm^2)	30.7 ± 1.8*	31.6 ± 2.3	31.6 ± 2.2	31.9 ± 2.4
BMC_{TF} (g)	32.0 ± 4.2	32.3 ± 4.1	32.6 ± 4.3	32.6 ± 5.5
$aBMD_{TF}$ (g/cm^2)	1.04 ± 0.11	1.02 ± 0.10	1.03 ± 0.10	1.02 ± 0.13
CSA_{FN} (mm^2)	148 ± 18	146 ± 20	147 ± 21	149 ± 20
CSMI (mm^4)	9730 ± 1870	9640 ± 2040	10070 ± 2240	10360 ± 2270
HAL (mm)	102 ± 6.4	102 ± 7.4	102 ± 5.8	103 ± 7.7
Tibia shaft				
Length (cm)	373 ± 20	380 ± 22	384 ± 19	382 ± 20
CSA (mm^2)	476 ±53†	489 ± 57*	496 ± 51	518 ± 68
BMC (mg/mm)	365 ± 48	366 ± 42	371 ± 37	380 ± 52
vBMD (g/ cm^3)	768 ± 68*	751 ± 54	750 ± 54	738 ± 61
PC (mm)	77.2 ± 4.3†	78.3 ± 4.6*	78.9 ± 4.9	80.5 ± 5.2
EC (mm)	49.3 ± 4.6‡	50.9 ± 4.7*	51.6 ± 4.4	53.2 ± 5.0
Cortical CSA (mm^2)	281 ± 39	281 ± 32	283 ± 30	290 ± 7.1
Cortical BMC (mg/mm)	323 ± 47	322 ± 38	326 ± 35	333 ± 49
Cortical vBMD (g/cm^3)	1150 ± 29	1150 ± 31	1155 ± 25	1147 ± 24
CSMI (mm^4)	41020 ± 9890†	43510 ±10360*	44570 ± 8750	48520 ± 12660

Data are given as mean ± SD. BA=Bone area; BMC=bone mineral content; aBMD=areal bone mineral density; CSA=Cross-sectional area; Cort, cortical; vBMD, volumetric bone mineral density;

FN=femoral neck; TF=total femur; CSMI=cross-sectional moment of inertia; HAL=hip axis length; PC= periosteal circumference; EC= endosteal circumference; SDB= short duration of breastfeeding; MDB= medial duration of breastfeeding; LDB=long duration of breastfeeding; VLDB=very-long duration of breastfeeding. * $p<0.05$; † $p<0.01$; ‡ $p<0.001$ compared to VLDB mothers.

Figure 1

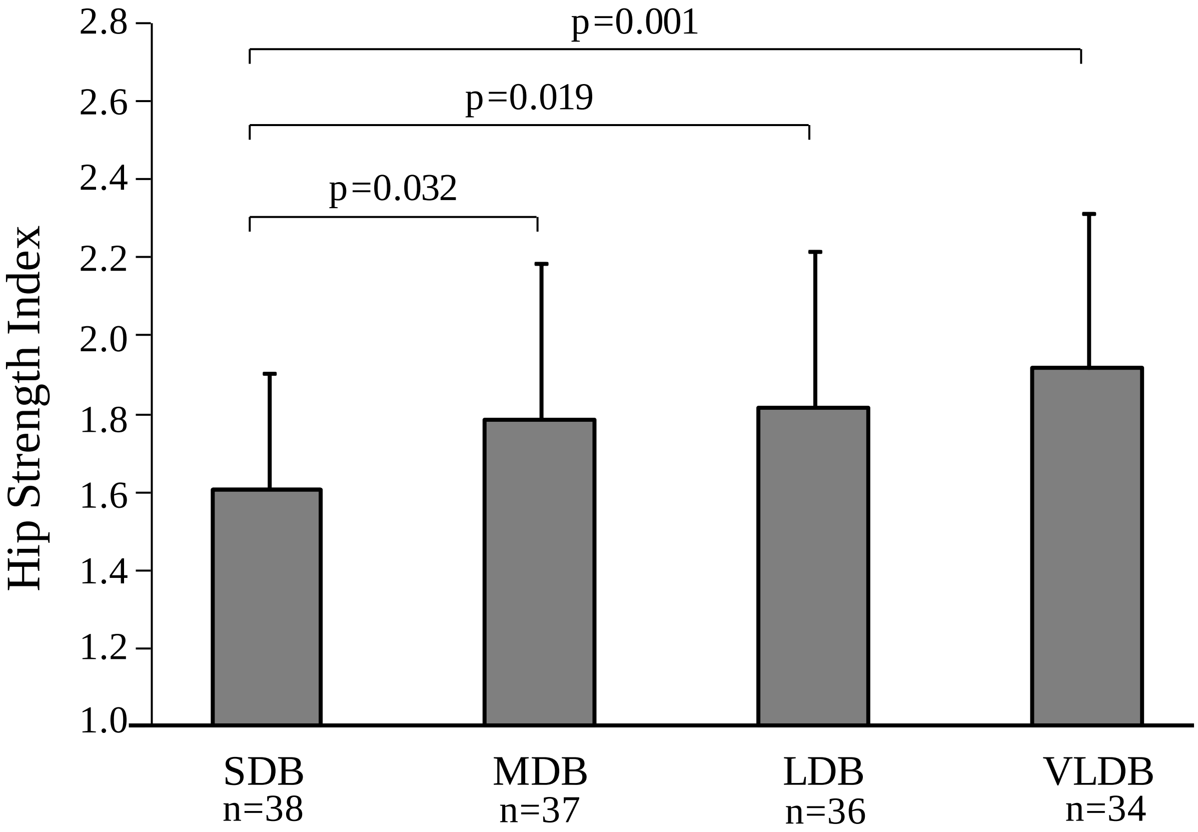
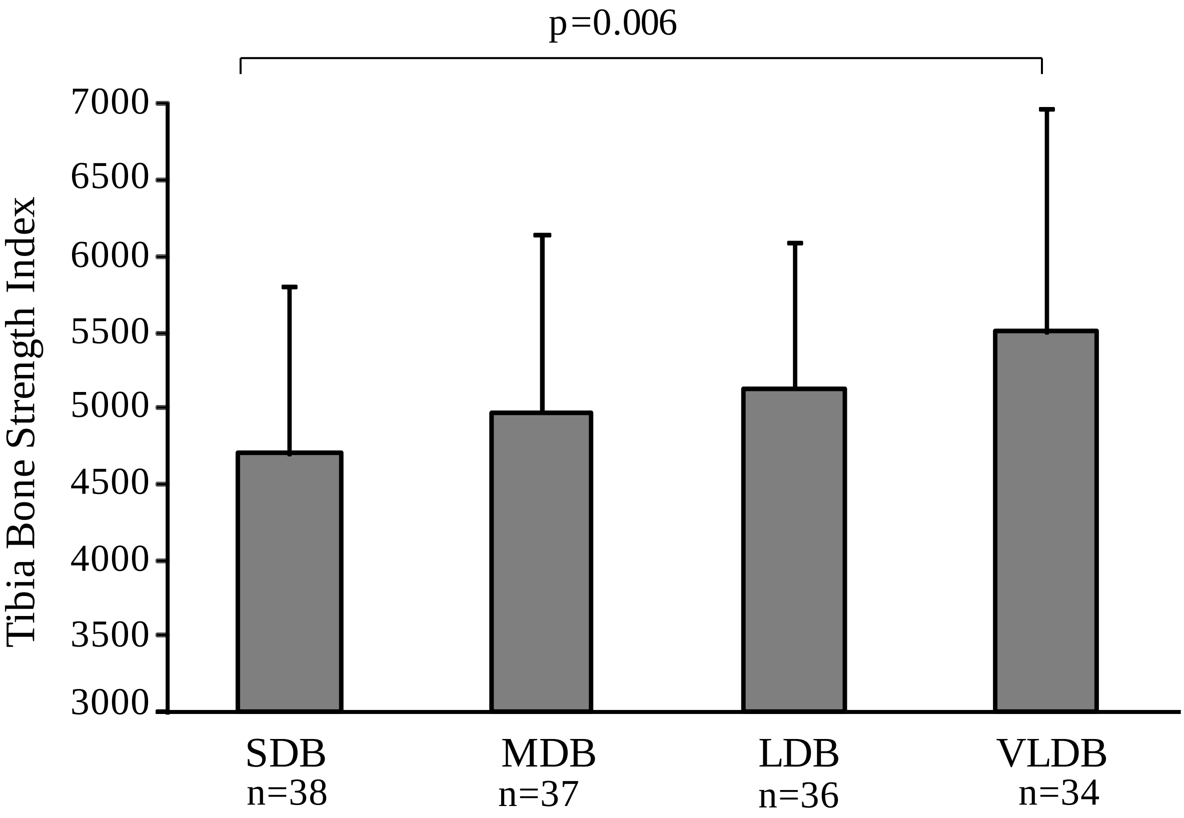

Hip Strength Index
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
p=0.001
p=0.019
p=0.032
SDB
n=38
MDB
n=37
LDB
n=36
VLDB
n=34

Figure 2


p=0.006
Tibia Bone Strength Index
7000
6500
6000
5500
5000
4500
4000
3500
3000
SDB
n=38
MDB
n=37
LDB
n=36
VLDB
n=34

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