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Bone Accrual in Children and Adolescent Non-Elite Swimmers: A 2-Year Longitudinal Study

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Abstract

Objective—To examine differences in bone mass between children and adolescents swimming competitively at non-elite levels (locally and regionally) and non-athletes and to assess changes in bone mass in these two groups over 24 months after taking into consideration several known confounders of bone mass.

Design—Observational prospective study.

Participants—White non-elite swimmers ($n = 128$) and non-athletes ($n = 106$) 8–18 years of age from Memphis, Tennessee, USA.

Main Outcome Measures—Participants underwent Dual-energy X-Ray Absorptiometry (DXA) to assess total body and hip Bone Mineral Content (BMC) at baseline and 12 and 24 months later.

Results—At baseline, swimmers had 4.2% and 6.1% higher adjusted BMC for the total body and hip, respectively, compared to non-athletes (p -values < 0.027). Averaging across assessment points, swimmers had 73.5 g and 2.2 g higher BMC for the total body and hip, respectively, than non-athletes. While there was a significant annual increase in total body and hip BMC in both groups (33.5 g and 0.7 g, respectively), there was no difference in annualized bone accrual between swimmers and non-athletes for either total body BMC (swim by time effect; $p = 0.213$) or hip BMC ($p = 0.265$).

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Conflicts of Interest

The authors declare no conflicts of interest.

Conclusions—Competitive swimming at non-elite levels during childhood and adolescence does not appear to compromise bone accrual.

Keywords

swimming; children and adolescents; bone mineral content; bone accrual; prospective study

INTRODUCTION

Children and adolescents who engage in high-impact sports (e.g., gymnastics and basketball) have greater bone mineral content (BMC) and bone mineral density (BMD) than non-athletes or those who engage in low-impact sports such as biking and swimming.^{1–3} A few prospective studies indicate a consistent pattern of greater bone mass gains over time in young athletes involved in high-impact sports compared to sedentary controls,^{4–6} thus emphasizing the sustained osteogenic effect of high-impact sports throughout growth.

Of concern is whether low impact sports such as swimming jeopardize bone accrual. Of particular interest is swimming, a popular sport in the US with over 340,000 individuals participating on USA Swimming teams alone.⁷ Cross-sectional studies indicate that, accounting for pubertal development, children and adolescent swimmers who compete at “elite” levels (i.e., nationally or internationally) have lower BMC and BMD at most measured bone sites including total body, hip, pelvis, and lumbar spine compared to athletes involved in high-impact sports^{2,8} and comparable or sometimes even lower than those of sedentary controls.^{1,9,10} In prospective studies, collegiate swimmers (> 17 years of age) accrue bone similarly to inactive controls despite high volume of training (>10 hours/week).^{11,12} Likewise, no differences were detected in bone accrual of children and adolescent elite swimmers (10–18 years of age; >13 hours/week training) compared to sedentary controls (2–3 hours/week physical activity) after 12 months¹³ and 36 months, respectively.⁹

Inconsistent results of cross-sectional and prospective studies (lower bone mass in swimmers compared to sedentary controls in cross-sectional studies but similar rates of bone accrual in prospective studies) may be due to the small number of prospective studies and small sample sizes (10–25 participants per group), as well as failure to consider differences between swimmers and controls in pubertal status,¹⁴ anthropometric characteristics (e.g., body weight, lean mass),^{15,16} calcium intake,¹⁷ high-impact activity,¹⁸ and the interactive effects of calcium and high-impact activity.¹⁹

No studies have assessed bone mass and bone accrual among children and adolescent swimmers who participate at non-elite levels (e.g., local and regional competitions rather than national and international competitions that are typical for elite swimmers). Although non-elite swimmers typically have fewer years of practice and less intense swim training (e.g., fewer hours per week and weeks per year) than elite swimmers²⁰ they nevertheless could experience training-related compromises to bone mass and accrual due to non-weight bearing characteristics of the sport. Thus, we hypothesized that non-elite swimmers would have lower total body and hip BMC and lower rates of bone accrual over two years compared to non-athletic controls, after adjusting for known confounders of bone mass including age, sex, pubertal status, weight, calcium, and high-impact activity.

METHODS

Design

A prospective observational comparison of bone mass and accrual was conducted in competitive non-elite swimmers and non-athletes over a 24-month period. Data were obtained from The Youth and Adolescent Health Osteo Outcomes (YAHOO) study.

Study Setting and Participants

Data were collected between 2000 and 2002 in Memphis, Tennessee, USA. Of 331 participants, 87 ethnic minorities (8 swimmers, and 79 non-athletes) were excluded due to low enrollment among swimmers. An additional ten participants were excluded due to discrepancies in reported swimming characteristics, resulting in a sample of 234 Non-Hispanic white swimmers and non-athletes (128 swimmers, and 106 non-athletes), 8–18 years of age.

Non-elite swimmers were members of a competitive team (USA Swimming, school teams, or club teams) for at least the preceding 12 months and planned to compete on a swim team for at least 24 months in the future. Non-athletes, hereafter referred to as controls, engaged in less than 60 minutes of physical activity per week and had not participated in any organized athletic activity for at least the past year.

Procedures

Parents provided written consent and children provided written assent. Parents and participants then completed several self-report measures including a self-assessment of pubertal development, a 12-month physical activity history, a past week calcium intake survey, and a 12-month dietary history and were interviewed about past week physical activity. The study was approved by the Institutional Review Board at The University of Memphis.

Measures

All measures were assessed at baseline and at 12- and 24-month follow-up as described below.

Height was measured to the nearest quarter-inch with a wall-mounted stadiometer (± 0.25 in). Weight was measured without shoes and outer clothing (i.e. jacket or heavy sweater) on a calibrated beam-balance scale (Detecto Electronics, Inc, Webb City, MO).

Pubertal status—Pubertal status was self-assessed using standardized drawings and descriptions based on the Tanner stages of pubertal maturation.^{21,22} Self-reported pubertal status by 9–17 year olds using Tanner staging agrees highly with physician ratings via physical examination.²³ For analyses, participants were subdivided into three pubertal groups: pre-puberty (Tanner stage I for breasts or genitalia and pubic hair), early puberty (Tanner stage II and III for breasts or genitalia), and late puberty (Tanner stage IV and V for breasts or genitalia).²⁴

Physical activity

a) Past week total energy expenditure: Past week total energy expenditure (kcal/day) and past week total daily energy expenditure adjusted for body weight (kcal/kg/day) were assessed using the Seven Day Physical Activity Recall (PAR).^{25,26} with adequate test-retest reliability and validity in children and adolescents.²⁶ Energy requirements for various intensity levels of physical activities (i.e. light, moderate, hard, or very hard), expressed as metabolic equivalents (METs), followed a classification scheme proposed by Sallis and colleagues.²⁵ Total daily energy expenditure (kcal/ day) was derived by multiplying MET values by hours spent for the correspondent activity, and the products were summed for each day and divided by 7. Total daily energy expenditure adjusted for body weight (kcal/kg/day) was estimated by dividing total daily energy expenditure by body weight.

b) Past year physical activity involvement: Past year physical activity involvement was expressed as a composite of frequency and duration of physical activity during the past 12 months using The One-Year Physical Activity Recall Assessment (YAR).^{27,28} From a list of 85 sports and games, participants chose their top ten most frequent physical activities conducted outside of physical education classes. From these activities we extracted high-impact and low-impact activities defined as those that produce mechanical strain on bone higher than one's body weight, (e.g., soccer, basketball) and lower than one's body weight, such as bicycling or swimming, respectively.²⁹ Physical activity involvement (hours/week) was calculated by summing the total minutes of activities performed weekly over the past year and dividing by 52.

Dietary intake

a) Past week calcium intake: Past week calcium intake was assessed using a dietary checklist of common sources of calcium in the American diet, including calcium-fortified foods (e.g., orange juice and bread) and foods frequently eaten by athletes, and the number of servings of each food type in the past week.³⁰ A standard serving size was listed for each food on the checklist (e.g., 1 oz, or 6 tbsp. for cheese, ½ cup for cottage cheese, ½ cup for fruits and vegetable, and 1 slice for breads). The number of servings per week of each food was multiplied by the corresponding calcium value for that food, and values were summed and divided by seven to obtain daily calcium intake over the past week. Test-retest reliability for two weeks (n = 56; *Intraclass correlation* [ICC] = 0.54) and validity (assessed as agreement with 6-day diet records [DRs]; n = 35; *Intraclass correlation* = 0.41) of the modified checklist were found to be adequate (agreement with DR; *ICC* = 0.3, *p* = 0.042) among a sample of female collegiate athletes.³¹ To increase accuracy of the checklist, line drawings of serving sizes were included, parents assisted participant in completing the checklist, and responses were verified before they left the laboratory.

b) Past year micronutrient intake and usual daily energy intake: Daily micronutrient intakes (without supplementation) and usual daily total energy intake during the previous 12 months were assessed with the Block 98 semi-quantitative Food Frequency Questionnaire (FFQ).^{32,33} The Block 98 includes 109 questions regarding typical food intake and supplement use over the past year. To increase accuracy in the current study, detailed instructions were given, portion size photographs were provided, participants were assisted

by parents, and responses were checked with parents and participants before leaving the laboratory.

Total and hip bone mineral content and lean mass—BMC instead of BMD was chosen as the bone mineral status measure in children and adolescents as BMD is influenced by growth-related changes including bone and body size.³⁴

Two independent scans of whole body and hip, respectively, were performed with Dual Energy X-Ray Absorptiometry (DXA) using a Hologic QDR-4500A. Total body BMC (g; estimated from BMC of legs, arms, pelvis, spine [vertebrae L2-L4], and ribs, excluding the skull) and total body lean mass (kg; estimated from lean mass of legs, trunk [pelvis, spine, and ribs], and arms) were generated from the whole body scan, whereas the hip BMC (g; estimated from BMC of femoral neck, trochanter, inter-trochanter, and Ward's triangle) was generated from the hip scan. Test-retest reliability of QDR-4500A was evaluated by comparing the DXAs on 14 collegiate baseball players taken approximately 30 minutes apart. Coefficients of variation for BMC were <1% when reported for same day and several months repeat measurements.

Statistical Analysis

We employed multiple linear regression (MLR) to generate predicted means of total body and hip BMC adjusted for confounders (e.g., age, sex, pubertal status, weight, calcium intake, and time spent in high-impact activity). Initial models also included two- and three-way interactions for calcium intake, high-impact activity, and swim status. Non-significant interactions ($p > 0.05$) were removed from final models.

Due to variability within and across groups in relevant exposures (i.e., differential average weekly swim time and engagement in high-impact activities of non-elite swimmers, recreational swimming reported by some controls), a propensity score matching analysis³⁵ was conducted. A sub-set of participants was used, including non-elite swimmers ($n = 35$) with reduced high-impact activity involvement and above average swim time and controls ($n = 35$) with limited high-impact activity involvement and limited swim time. Participants were matched on age, sex, pubertal status, and lean mass to allow for a similar distribution of covariates.

Independent *t*-tests were conducted to investigate missing patterns of outcome variables (total body and hip BMC) at 12 and 24 months on baseline predictor variables. Using Bonferroni-adjusted alpha-levels of 0.007 (0.05/7), comparisons between missing and non-missing total body BMC and hip BMC values were performed for each predictor.

We examined changes in bone accrual of swimmers and non-athletes over a 24-month period, controlling for age, sex, pubertal status, weight, calcium, and high-impact activity. Data from baseline, 12 months, and 24 months were analyzed using a linear mixed model approach.³⁶ Total body and hip BMC were the outcome variables. Predictors included as fixed effects were swim status (swimmer or non-swimmer), time, swim status by time interaction, sex, pubertal status, sex by pubertal status, weight, calcium, and high-impact activity (all measured at baseline and 12 and 24 months follow-up). Interaction term sex by

pubertal status was introduced in the model to account for possible differential effects in bone accrual between males and females during puberty. Age and age-squared were initially considered as random effects to account for variability between participants in bone accrual. Standard error for random effects could not be estimated for age and age-squared, hence significance could not be estimated and the linear model was considered the final model. Statistical significance for all analyses was set at $\alpha = 0.05$ (two-tailed) except for analyses of missing patterns ($\alpha = 0.05/7$). All analyses were conducted using SAS (Statistical Analysis Software; version 9.3 for Windows; SAS Inc., Cary, NC, USA).

RESULTS

Baseline Characteristics

Characteristics at baseline of the non-elite swimmers and controls are presented in Table 1. Swimmers compared to controls were on average a year younger ($p = 0.015$) and in an earlier pubertal stage ($p = 0.012$). A total of 47 females (24 controls and 23 swimmers) were post-menarcheal (Tanner stage V). While non-elite swimmers weighed less ($p = 0.002$), they were similar in height and lean mass (p -values > 0.137). Compared to controls, non-elite swimmers had higher energy expenditure per kg body weight ($p < 0.001$) and reported greater time participating in low-impact, high-impact, and total physical activity (p -values < 0.001). Swimmers averaged 5.7 hours/week of training. Regarding nutritional profile, non-elite swimmers reported a higher daily calcium intake than controls ($p = 0.001$), whereas vitamin D and total energy intake were comparable (p -values > 0.141).

Baseline BMC Differences Between Swimmers and Non-Athletes

Non-elite swimmers compared to controls had higher adjusted total body and hip BMC (4.2% and 6.1%, respectively; $p < 0.027$; Cohen's $d = 0.27$; Table 2).

Models were adjusted for age, sex, pubertal status, weight, calcium intake, and high-impact activity. Multicollinearity was not a concern (variance inflation factor < 4.5). In the propensity score matched analysis, a statistically significant difference was observed between non-elite swimmers and controls for total body ($p = 0.001$), but not hip BMC ($p = 0.120$; Table 2).

BMC Changes Over 24 Months

Of the 234 participants, 155 (66%) provided all three BMC assessments, 41 (18%) provided BMC assessments at baseline and 12-month follow-up, and 3 (1%) provided BMC assessments at baseline and 24-month follow-up. Participants who did not return for follow-up at either 12 months or 24 months were more likely to be controls and approximately one year younger than those who did. Participants who provided or did not provide follow up data were similar on all other baseline characteristics (data not shown).

Collapsing across assessment points, swimmers averaged 73.5 g and 2.2 g higher BMC for the total body and hip, respectively, than non-athletes (Table 3). Main effect for time indicates a significant annual increase in bone accrual for total body and hip BMC for both swimmers and non-athletes (33.5 g and 0.7 g, respectively). There was no significant

difference in annualized bone accrual between swimmers and non-athletes for either total body BMC (swim by time effect; $p = 0.213$) or hip BMC ($p = 0.265$).

DISCUSSION

To our knowledge, this is the first prospective study to evaluate bone mass and accrual of non-elite child and adolescent swimmers. The results extend previous cross-sectional and prospective studies among elite swimmers (i.e., those who train at intense levels that are typical of those competing nationally or internationally). These studies typically showed no osteogenic benefit of swimming over being sedentary, indicated by swimmers having lower or similar bone mass at several sites, and similar rates of bone accrual, compared to non-athletes.^{2,8,9,11–13,37} The current study compared total body and hip bone mass of child and adolescent non-elite swimmers to non-athletic controls at baseline and assessed changes in bone mass over time. Our results indicate that swimmers had slightly higher (4–6%) BMC at baseline than non-athletes, but similar accrual over two years.

While these data do not support an adverse effect of swimming on bone mass (i.e., swimmers did not have lower absolute BMC levels or accrue BMC over time at lower rates than non-athletes), the lack of difference between groups in bone accrual is consistent with swimming, as a non-impact activity, providing limited osteogenic stimulation. Greater bone accrual in swimmers might be expected given that they engaged in nearly twice as much high-impact activities (4.5 vs. 2.4 hours/week on average, respectively) as non-athletes, such as basketball, soccer, and football. Of note, however, is that differences between swimmers and controls are not confounded by differences in physical activity. Our primary analyses statistically adjust for the effects of high impact activity, as well as several other confounders, including age, sex, pubertal status, weight, and calcium intake. Further, the pattern of results remained very similar in propensity score-matched sensitivity analyses that restricted comparisons to swimmers engaged in low levels of high impact activity and controls who did not engage in recreational swimming, to maximally isolate the effect of swimming on bone mass.

Our results add to a small prospective literature on bone growth in children and adolescent competitive swimmers. For example, Maïmoun and colleagues¹³ reported an increase in bone mass after one-year follow-up in female swimmers (10–18 years of age) who swam competitively for 6.6 years and trained for 15 hours/week, however, they accrued bone at the same rate as the controls (age-matched with < 3 hours/week leisure physical activity) when adjusting for age, fat mass and lean mass. Similar results were reported in a study conducted in 11 to 13 years of age female competitive swimmers (13 hours/week training; 2.3 years of training) and non-athletic controls (2 hours/week physical activity) who gained bone mass over 36 months, although no difference was detected between the groups.⁹ Lack of differences in bone accrual between swimmers and controls in the study by Maïmoun et al.¹³ may have been due to a relatively short follow-up period (one year) or inadequate statistical power due to the small sample size (swimmers, $n=24$; age-matched controls, $n=24$). In comparison, Czezelewski et al.⁹ conducted a three-year follow-up. However, adjustment for confounders of bone is not reported, which tempers the confidence of these findings. In both

studies, sample size was small (20–24 participants per group) and this limited the control for confounders of bone mass (e.g., calcium, high-impact activity).

Several limitations of the current study should be noted. First, sample homogeneity resulted from a combination of lack of random sampling and geographical uniformity. Second, there was significant drop out over two years of follow-up. However, our linear mixed model statistical analysis approach included all participants in analyses regardless of missing data status, and missingness analysis indicated few differences in baseline characteristics as a function of missingness. Third, data were collected from 2000–2002, and it is possible that physical activity patterns of children and adolescents (e.g., physical inactivity level among the general population, training patterns for non-elite swimmers), may have changed since then, although we are not aware of evidence of such changes. Fourth, physical activity magnitude could not be calculated from the One-Year Physical Activity Recall Assessment (YAR) questionnaire as it only estimates frequencies and length of physical activities during the past year. Fifth, because swimmers and controls were not randomly sampled, one cannot dismiss the possibility of selection bias. For example, reverse causation could occur such that swimmers may have self-selected into the sport due to some physical characteristics (e.g., agility, physical conditioning) associated with bone mass. Lastly, while we performed a propensity matching analysis to reduce bias by eliminating intra- and intergroup variability in relevant exposures (i.e., differential swim time and involvement in high-impact activities of non-elite swimmers; recreational swimming reported by some controls), we may have been underpowered to detect differences in bone mass (35 participants per group).

Our study demonstrates that children and adolescents who engage in non-elite, competitive swimming have similar total body and hip bone mass and bone accrual compared to non-athletic controls. Our findings suggest that non-elite swimming does not compromise bone accrual in this population, but to obtain an osteogenic benefit, swimming needs to be supplemented with high-impact activity. However, more research is warranted to explore the influence of this sport on bone accrual and to compare it to non-swimming athletes using broader and more representative sampling, and broader measures of skeletal structure and quality.

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Table 1

Characteristics of Non-Elite Swimmers and Controls at Baseline

Variable	Swimmers	Controls	<i>p</i> [*]
	%	%	
Sex (male)	34	41	0.329
Pubertal status			
Pre-puberty (Tanner I)	25	16	0.012
Early puberty (Tanner II–III)	31	21	
Late puberty (Tanner IV–V)	44	63	
	<i>Mean ± SD</i>	<i>Mean ± SD</i>	
Age (years)	12.8 ± 2.9	13.8 ± 3.2	0.015
Weight (kg)	48.9 ± 15.7	56.4 ± 19.5	0.002
Height (cm)	155.8 ± 15.7	158.8 ± 15.8	0.153
Lean mass (kg)	32.2 ± 10.5	34.4 ± 12.0	0.137
Calcium intake (mg/day)	1100 ± 539	875 ± 504	0.001
Vitamin D intake (µg/day)	216 ± 160	191 ± 140	0.235
Energy intake (kcal/d)	2208 ± 847	2030 ± 903	0.141
Low-impact activities (h/wk)	8.0 ± 4.3	4.4 ± 4.1	< 0.001
High-impact activities (h/wk)	4.5 ± 4.9	2.4 ± 2.1	< 0.001
Total physical activities (h/wk)	12.2 ± 6.9	6.4 ± 4.8	< 0.001
Energy expenditure (kcal/kg/day)	39.7 ± 5.7	34.5 ± 3.3	< 0.001

* *p*-values from between group t-test or chi-square test of independence.

Due to occasional missing data, sample size varied across for swimmers and controls.

Sample size for swimmers differed: age (n = 128); weight (n = 128); height (n = 128); lean mass (n = 128); calcium (n = 127); vitamin D (n = 118); energy intake (n = 118); low-impact activities (n = 121); high-impact activities (n = 116); total physical activities (n = 122); energy expenditure (n = 127).

Sample size for controls differed: age (n = 106); weight (n = 106); height (n = 106); lean mass (n = 106); calcium (n = 105); vitamin D (n = 94); energy intake (n = 94); low-impact activities (n = 92); high-impact activities (n = 80); total physical activities (n = 93); energy expenditure (n = 105).

Table 2

Adjusted Predicted Means for Total Body and Hip BMC of Children and Adolescent Non-Elite Swimmers and Controls at Baseline

	BMC (g)	Swimmers	Controls	<i>p</i>
		<i>Mean ± SE</i>	<i>Mean ± SE</i>	
Whole set ⁽¹⁾ (<i>n</i> = 195)	Total body	1201 ± 15.1	1152 ± 18.9	0.027
	Hip	26.0 ± 0.4	24.5 ± 0.5	0.005
Matched set ⁽²⁾ (<i>n</i> = 70)	Total body	1104 ± 26.1	959.4 ± 41.9	0.011
	Hip	23.8 ± 0.5	22.0 ± 0.9	0.120

BMC: Bone Mineral Content

Data were adjusted for age, sex, pubertal status, weight, calcium intake, and high-impact activity.

⁽¹⁾ Whole set: 115 swimmers and 80 controls.

⁽²⁾ Matched set: 35 swimmers and 35 controls. Matching was performed among participants with reduced time involvement in high-impact activities; among those, were selected only swimmers with the greatest time involvement in swimming and controls with the lowest non-team involvement in swimming.

Table 3
Predictive Models of Bone Accrual for Total Body and Hip BMC over 24 Months

Effect	Total Body BMC			Hip BMC		
	Estimate $\pm$ SE	t	p	Estimate $\pm$ SE	t	p
Intercept	-34.0 $\pm$ 48.6	-0.7	0.486	6.3 $\pm$ 1.2	5.4	<0.001
Time	33.5 $\pm$ 8.6	3.9	<0.001	0.7 $\pm$ 0.2	3.3	0.001
Swim status	73.5 $\pm$ 27.2	2.7	0.007	2.2 $\pm$ 0.7	3.3	0.001
Swim status by time	-13.2 $\pm$ 10.6	-1.3	0.213	-0.3 $\pm$ 0.3	-1.1	0.265
Pubertal status						
Pre-puberty	-192.0 $\pm$ 30.0	-6.4	<0.001	-3.6 $\pm$ 0.7	-4.9	<0.001
Early puberty	-166.5 $\pm$ 20.4	-8.2	<0.001	-2.5 $\pm$ 0.5	-5.0	<0.001
Late puberty (ref)						
Sex						
Male	106.4 $\pm$ 28.7	3.7	<0.001	4.8 $\pm$ 0.6	7.6	<0.001
Female (ref)						
Pubertal status by sex						
Pre-puberty by male	-71.3 $\pm$ 37.7	-1.9	0.060	-4.1 $\pm$ 0.9	-4.4	<0.001
Early puberty by male	-42.4 $\pm$ 29.4	-1.4	0.150	-2.9 $\pm$ 0.7	-4.0	<0.001
Weight (kg)	23.0 $\pm$ 0.8	30.4	<0.001	0.3 $\pm$ 0.0	19.2	<0.001
Calcium (mg)	0.02 $\pm$ 0.01	1.4	0.168	1.1e-4 $\pm$ 3.2e-4	0.4	0.728
High impact (h/wk)	-1.1 $\pm$ 1.7	-0.6	0.543	0.03 $\pm$ 0.04	0.7	0.460

Fixed effects: swim status, time, swim status by time, sex, pubertal status, weight, calcium intake, and high-impact activity.

Swim status was effect coded as swimmer = 1, control = 0; sex as male = 1, female = 0; pubertal status as pre-, early-, & late-pubertal status (dummy coding: late-pubertal status as reference).

Model fit for total body BMC ($-2 \log \text{likelihood} = 5722.1$, Akaike information criterion = 5750.1).

Model fit for hip BMC ($-2ll = 2365.3$, AIC = 2393.3).