AN ABSTRACT OF THE DISSERTATION OF

Todd A. Rinder for the degree of Doctor of Philosophy in Exercise and Sport Science presented on March 4, 2004.
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Discordance in bone mass between young adult swimmers and soccer players may be a direct result of differences in bone loading patterns that influence bone mineralization during growth. Our aim was to evaluate whether sports participation (soccer and swimming) had an independent effect on bone mass accrual at the hip and lumbar spine in adolescent female athletes. We recruited boys and girls 10 to 14-years of age from Corvallis, Albany, Sweet Home, Salem, Eugene, and the greater Portland area. Bone mineral content (BMC, g) and bone mineral density (BMD, g/cm^2) of the proximal left hip, spine, and whole body were assessed by dual energy x-ray absorptiometry (Hologic QDR 4500A; Hologic Inc., Waltham, MA, USA). We used ANCOVA and report that baseline BMC and BMD values of girl soccer players at the greater trochanter were significantly higher compared to controls and the swim group, and femoral neck BMC was significantly greater than the swimmers. At baseline, all boy groups were similar at the hip and spine. After 12-months, ANCOVA was also used to assess absolute change for BMC and BMD at the hip and spine. The girl soccer players had significantly more BMC and BMD at the greater trochanter as well as total hip BMD and lumbar spine BMC compared to the swimmers, but not the controls. The girl control group showed a significantly greater 12-month change for femoral neck and greater trochanter BMC than swimmers. Overall, the girl swimmers

demonstrated a lower accumulation of bone mass during the 12-month study period. As for the boys, soccer players had a significantly higher 12-month change for femoral neck BMC than swimmers, but were similar at the spine. There were no differences between the boy control subjects and the swimmers for 12-month change values at the hip and spine. While preliminary and limited by the small sample size, our results indicate that after controlling for growth, soccer players gained significantly more BMC at the femoral neck than swimmers. Furthermore, exposing the young skeleton to impact loading exercise has site-specific benefits at the hip whereas prolonged training in a non-weight bearing environment may compromise skeletal acquisition.

Bone Gains in Adolescent Athletes and Non-Athletes

By

Todd A. Rinder

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Todd A. Rinder, Author

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INTRODUCTION

Osteoporosis is a disease characterized by low bone mass and structural deterioration of bone tissue, leading to bone fragility and an increased susceptibility to fractures of the hip, spine, and distal forearm. Ten million people are estimated to already have osteoporosis in the United States—women make up 8 million (80%) and men 2 million (20%). Additionally, 34 million are estimated to have osteopenia (low bone mass) and people the age of 50 years and older comprise 55% of this group. Annually, 1.5 million fractures can be attributed to osteoporosis with the following breakdown: 300,000 hip fractures, 700,000 vertebral fractures, 250,000 wrist fractures, and 300,000 fractures at other sites. Of the hip fracture patients, 24% aged 50 years and over will die within the following year, only 15% will be able to walk unaided across a room at six months, and one quarter that were ambulatory before the hip fracture will require long term care. Thus, costs associated with treatment are staggering and reaching crisis proportions. Specifically, in the United States, 47 million dollars are directly spent each day for care in hospitals and nursing homes following an osteoporosis related fracture.

Because bone loss occurs without noticeable symptoms, osteoporosis is often referred to as a "silent disease". Risk factors for osteoporosis include an inactive lifestyle, low lifetime calcium intake, being female, estrogen deficiency as a result of amenorrhea or menopause, advanced age, and genetics. There are steps to prevent osteoporosis: 1) a balanced diet rich in Vitamin D and calcium, 2) weight bearing exercise, and when appropriate 3) bone density testing and medication. The good news is that the first two steps are modified by a healthy lifestyle and early intervention may offset the development of osteoporosis by improving peak bone mass, the maximum amount of bone mass in the young adult skeleton. While osteoporosis is thought of as a disease of aging, physical activity at an early age is important because by the age of 18 skeletal growth is nearly complete and by age 20 approximately 98% of bone mass is acquired and then a small increase in bone mass occurs through the third decade of life. Sixty to eighty percent of bone acquisition is genetically determined, but there is a growing body of evidence that exercise patterns associated with sports before and during puberty contribute to peak bone mass accrual.

Bone Mass and Swimming

Although swimmers are strong powerful athletes, the vigorous physical activity associated with swimming occurs in a buoyant environment that does not mechanically load the skeleton. Grimston et al. (1993) tested the hypothesis that different mechanical loading patterns play a role in the acquisition of bone mineral density (BMD) in boys and girls. The researchers compared subjects participating in impact loading sports (sports that generate ground reaction forces 3 times body weight or greater at landing) to active loading sports (sports that do not generate ground reaction forces). The impact-loading group had significantly higher BMD at the femoral neck and the lumbar spine was higher but not significant. Thus, children engaged in active loading sports (i.e. swimming) had femoral neck BMD that was significantly lower than children participating in weight bearing sports. Limitations to this study were low sample size resulting in reduced statistical power and it was a cross sectional study.

Subsequent work in young adult athletes compared loading patterns of female collegiate gymnasts, volleyball players, and swimmers comparing them to a control group (Fehling et al., 1995; Taaffe et al., 1997). After adjusting for height and weight, both gymnasts and volleyball players had BMD that was significantly higher at the lumbar spine, femoral neck, and total body compared to the swimmers and control subjects. The swim and the control groups were similar at all sites, even after adjusting for height and weight. Results from Taaffe et al. (1997) investigation of eumenorrheic collegiate females were similar at the femoral neck and in addition showed a significant difference at the greater trochanter with gymnasts greater than both the control subjects and the swimmers. Also, the results revealed similar values among the groups for the whole body and lumbar spine BMD plus the BMD values of swimmers did not differ appreciably from controls. Taaffe et al. (1999) further studied elite male collegiate swimmers and reported that BMD of the hip, spine, and whole body did not differ significantly between the swimmers and control subjects. Thus, these studies reveal that the athletes who engage in high magnitude loading of the skeleton of short duration exhibit site-specific BMD change at the hip and spine, while swimming does not appear to benefit the skeleton in elite athletes. A primary question is whether the lower bone mass values in swimmers develops due to long term exposure to a non-weight bearing environment during growth as most athletes begin their training prior or during the adolescent growth spurt.

Courteix et al. (1998) investigated the association of impact loading versus non-impact loading sports on the effects of BMD acquisition in pre-pubertal girls (Tanner 1). Specifically, the researchers examined 3 years of intense sports training on BMD at the hip and spine in gymnasts, swimmers, and control subjects. The researchers reported that the gymnasts had significantly higher BMD at the femoral neck (15% more) and lumbar spine (12% more) compared to swimmers and control subject while the control subjects and swimmers were similar at all measured sites. The main result was that activity, with respect to loading patterns, contributed to BMD enhancement in pre-pubertal athletic girls and swimming is not the physical activity that will optimize peak bone mass in the growing skeleton.

Duncan et al. (2002) had a novel approach to examine triathletes who combine swimming, cycling, and running into their exercise routine. Adolescent girls grouped by swimming, cycling, running, triathlete, and control were measured at the whole body, hip, and spine. Unadjusted means indicated that runners had higher BMD at all sites. Adjusting for lean tissue mass, years since menarche, and years of specialized training, runners were significantly greater from all groups at the femoral neck whereas at the lumbar spine the runners were only significantly greater from triathletes. At the femoral neck triathletes were 11% higher than swimmers and the triathletes time spent swimming and cycling comprised 75% of their time training, yet a higher BMD value at the femoral neck was achieved with only a modest training volume.

Hence, cross sectional studies provide evidence that swimming does not provide impact stimulus at the hip and spine. Lower bone mass has been reported at the hip and spine in swimmers when compared to athletes whose training requires mechanical loading of the skeleton, and similar hip and spine bone mass has been reported when compared to controls. However, the subjects were college age (18-24 years) and did not examine the athlete during puberty—a critical growth period for bone mass accrual.

Bone Mass and Soccer

According to FIFA (Fédération Internationale de Football Association), there are over 240 million active soccer players – one in every twenty-five of the world's population. Therefore, a large population is engaged in the vigor of soccer training—sprinting, jumping, and quick changes of direction that mechanically load the skeleton, which may stimulate bone accrual at the hip and spine. Alfredson et al. (2000) designed a study to learn if female soccer players showed signs of skeletal adaptation at the hip and spine. The results indicated that soccer players had significantly higher BMD at the femoral neck (14%), greater trochanter (13%), and lumbar spine (11%) than controls. However, limitations include small sample size, no mention of menstrual status, use of contraceptive, years of soccer participation, and calcium intake. Düppe et al. (1996) examined at a broader age range of female soccer players—junior (13-17 years), senior (18-28 years), and former (>40 years) to further clarify the relationship of physical activity and BMD development and maintenance. The results indicated that the junior and senior soccer players had significantly higher BMD values at the hip. Adjusting for age and BMI, soccer players were 10% higher at the femoral neck, 11% higher at the greater trochanter, and 5% higher at the lumbar spine than a control group. The former soccer players were higher at the hip but not the spine. In addition, the former soccer players retained higher BMD values than age matched controls thus indicating the potential that early intervention may enhance peak bone mass even after the cessation of soccer participation. Söderman et al. (2000) examined female adolescent soccer players and found significantly higher BMD values at the hip and spine compared to a control group. Further division of soccer players into a young group (< 16 years) and old group (> 16 years) revealed that only greater trochanter BMD was significantly different from controls in the young, while the older group had significantly higher BMD at the femoral neck, greater trochanter, and lumbar spine. These results raise a couple questions: 1) Is late adolescence more responsive to mechanical loading? and 2) What if years of participation are different, especially if participation was prior to menarche?

Exploring the possibility that duration of training may have an association on the skeleton, Karlsson et al. (2001) examined 67 male soccer players who competed at different league levels (professional, amateur, and recreational). The results confirmed previous studies that loading is region specific. When examining the subjects that were training up to 6 hrs/wk (recreational), femoral neck BMD increased 3.3% per hour of activity whereas subjects exercising up to 12 hrs/wk (professional) only showed an improvement of 0.7 % per hour of activity. Thus, in this study exercising greater than 6 hours per week does not confer an added benefit to the femoral neck in male soccer players. Using the above subjects and including former soccer players (categorized into < 39 years, 40-49 years, 50-59 years, 60-69 years, and 70-85 years) and control subjects, Magnusson et al. (2001) examined femoral neck BMD over the span of several decades. The researchers concluded that increased activity of soccer players improved BMD values at the femoral neck compared to control subjects, and the former soccer players continued the difference until the seventh decade—a point where no differences were observed. High bone mineral content (BMC) and BMD values at the hip and spine were found in male soccer players (22.3 years) that began their participation prior to puberty (12 yrs) compared to a control group (Calbert et al., 2001). BMC values were 13%, 24%, and 23% higher at the lumbar spine, femoral neck, and greater trochanter and BMD values were 10%, 215, and 21% higher, respectively. The authors concluded that long-term participation, particularly when starting at a prepubertal age, confers higher BMC and BMD values at clinically important sites.

Thus, cross sectional studies examining gymnasts, soccer players, swimmers and control subjects support an association of increased BMD values at the hip and spine with impacting loading, whereas active loading is not associated with skeletal adaptations. This discordance in bone mass may be a direct result of differences in bone loading patterns that influence bone mineralization during growth.

Statement of Purpose

To date, there are no longitudinal investigations that have examined the association of non-impact and impact activities on bone acquisition during youth. Our aim was to evaluate whether sports participation (soccer and swimming) had an independent effect on bone mass accrual at the hip, lumbar spine, and whole body in young adolescent boys and girls. We studied boys and girls separately due to known differences in timing of puberty and examined young athletic boys and girls and control subjects at baseline and over 12-months. We asked the following research questions: 1) At baseline, are there differences in bone mass between adolescent soccer players, swimmers, and control subjects? 2) Over 12-months, is bone mass accrual greater in soccer players than swimmers and controls? and 3) Over 12-months, is bone mass accrual in control subjects greater than swimmers? Based on the literature we hypothesized the following: 1) at baseline there would be differences bone mass; 2) soccer players would have a greater bone mass accrual at the hip and spine than control subjects and swimmers; and 3) swimmers and control subjects would have no difference in bone mass at the hip and spine. If soccer players gain more bone mass and swimmers gain less bone mass, then we can develop a simple impact exercise program to include during warm-up activities for swimmers that may contribute to improved bone acquisition at this critical time in growth.

Chapter 2

BONE GAINS IN ADOLESCENT FEMALE ATHLETES AND NON-ATHLETES

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Abstract

Purpose: Discordance in bone mass between young adult swimmers and soccer players may be a direct result of differences in bone loading patterns that influence bone mineralization during growth. Our aim was to evaluate whether sports participation (soccer and swimming) had an independent effect on bone mass accrual at the hip and lumbar spine in adolescent female athletes. **Methods:** We recruited girls 10 to 14-years of age from Corvallis, Albany, Sweet Home, Salem, Eugene, and the greater Portland area. Bone mineral content (BMC, g) and bone mineral density (BMD, g/cm^2) of the proximal left hip, spine, and whole body were assessed by dual energy x-ray absorpiometry. **Results:** At baseline we used ANCOVA and report that BMC and BMD values of soccer players at the greater trochanter were significantly higher compared to controls and the swim group, and femoral neck BMC was significantly greater than the swimmers. After one year, ANCOVA was also used to assess absolute change for BMC and BMD at the hip and spine. The soccer players had significantly more BMC and BMD at the greater trochanter as well as total hip BMD and lumbar spine BMC compared to the swimmers, but not the controls. The control group showed a significantly greater 12-month change for femoral neck and greater trochanter BMC than swimmers. Overall, the swimmers demonstrated a lower accumulation of bone mass during the 12-month study period. **Conclusion:** While preliminary and limited by the small sample size, our results indicate that after controlling for growth, exposing the young skeleton to impact loading exercise has site-specific benefits at the hip whereas prolonged training in a non-weight bearing environment may compromise skeletal acquisition. **Key Words:** SOCCER, SWIMMING, EXERCISE, OSTEOPOROSIS

Introduction

Osteoporosis is a disease characterized by low bone mass and structural deterioration of bone tissue, leading to increased fragility, and susceptibility to fracture. There are over 300,000 hip and 700,000 vertebral fractures annually in the United States and the associated expenditure exceeds 17 billion dollars. While osteoporosis is often considered a disease of aging, lifestyle choices during growth may offset the development of osteoporosis by improving peak bone mass, the maximum amount of bone mass attained in the young adult skeleton. Since 60-80% of peak bone mass is genetically determined, up to 40% may be altered by lifestyle. Thus, exercise patterns that load the skeleton before and during puberty contribute to peak bone mass accrual [9,36,38] and the increase in peak bone mass may reduce the risk of osteoporotic fractures later in life [35].

Physical activity, specifically impact exercise, is associated with higher peak bone mass [10,29,32]. Both cross sectional and retrospective studies have compared young athletes who participate in sports with different impact loading patterns to nonathletic controls [4,27]. Fehling et al. [8] showed that bone mineral density (BMD) of the femoral neck (hip) and lumbar spine were greatest in collegiate gymnasts and volleyball players but that swimmers and controls had similar BMD at the femoral neck and lumbar spine. Data from our laboratory demonstrate that collegiate female swimmers have lower hip bone mass than both gymnasts and controls [32]. Although swimmers are strong powerful athletes, active muscle loading associated with swimming may not be enough to offset the non-weight bearing effect of the buoyant water environment. Perhaps the age at which an athlete begins swimming has an effect of decreasing bone mineralization. Studies of soccer players also support the hypothesis that impact activity is osteogenic. Söderman et al. [30] showed that hip BMD of high school aged female soccer players was 14.8% to 16.5% higher than controls, while Alfredson et al.

[1] reported higher spine BMD (4.8%) in collegiate soccer players versus controls. This discordance in bone mass between swimmers, gymnasts, and controls in young athletes may be a direct result of differences in bone loading patterns that influence bone mineralization during growth.

In this study, our aim was to evaluate whether sports participation (soccer and swimming) had an independent effect on bone mass accrual at the hip, lumbar spine, and whole body. We studied young athletes and controls at baseline and over 12-months and asked the following research questions: 1) At baseline, are there differences in bone mass between adolescent soccer players, swimmers, and control subjects? 2) At 12-months, is bone mass accrual greater in soccer players than in swimmers and controls? and 3) At 12-months, is bone mass accrual in control subjects greater than in swimmers? Based on the literature we hypothesized the following: 1) at baseline there would be differences in bone mass between groups; 2) soccer players would have greater bone mass accrual at the hip and spine than control subjects and swimmers; and 3) control subjects would have greater bone mass accrual at the hip and spine than swimmers. If soccer players gain more bone mass and swimmers gain less bone mass, then we can develop a simple impact exercise program for swimmers to include during warm-up activities that may contribute to improved bone acquisition at this critical time in growth.

Materials and Methods

Participants

Girls 10 to 14-years of age were recruited from Corvallis, Albany, Sweet Home, Salem, Eugene, and the greater Portland area. For inclusion, participants met the following criteria: 1) member of a year-round swimming team, member of a year-round soccer club, or active but not participating in any year round sport; 2) in grades 6 through 8; 3) a non-smoker; 4) not taking medications that affect bone metabolism;

5) able and willing to participate for 12 months; and 6) free of metabolic and/or respiratory disease and orthopedic problems. Thus, forty-two girls were enrolled into the study and placed into one of three groups: 1) control, 2) soccer, and 3) swim. The Oregon State University Institutional Review Board and the Oregon State Board of Radiology approved the research protocol. Both the parent and the subject gave written informed consent to participate before entry into the study.

One subject did not return for follow-up testing due to continuously missing appointments. Thus, forty-one female adolescent athletes (13 controls, 11 soccer players, and 17 swimmers) completed the longitudinal study. Of these, 39 were white and 2 were Asian. At baseline, groups were similar for age, height, and weight (Table 1). After 12-months, all groups were similar for a change in height, but the soccer players had a significantly greater 12-month change in weight than both the control subjects and swimmers.

Bone Measurements

Bone mineral content (BMC, g) and bone mineral density (BMD, g/cm^2) of the proximal left hip, spine (AP), and whole body were assessed by dual energy x-ray absorpiometry (Hologic QDR 4500A; Hologic Inc., Waltham, MA, USA). We report BMC values because bone mass and area do not increase proportionally during growth [26], and we provide BMD data since the majority of studies report BMD values although we acknowledge that changes in proportion of cortical and trabecular bone (size and thickness) that occur during growth affect BMD measurement [13]. Because bone accretion varies regionally in the growing skeleton [26], whole body scans were employed to detect change in overall bone mass. All scans were performed in fast array mode and analyzed using Hologic QDR Software for Windows 98 (ver 11.2). To maintain the hip in 30 degrees of internal rotation, a positional device was used. Lumbar spine scans were performed with the subject supine and a foam block placed under the legs to maintain 90 degrees of flexion at the hips and knees and decrease the lordotic curve of the lumbar spine. A licensed radiologic technician performed all scans.

Anthropometric Measurements

Height and weight were measured without shoes in exercise clothing (shorts, t-shirt, and/or sweat suit). Height was measured to the nearest mm using a wall-mounted stadiometer (Seca Model S-220; Hanover, MD, USA) and weight was measured to the nearest 0.1 kg (Seca Alpha Model #770). Two measurements were taken for each variable and averaged. If a measure was greater than 4 mm for height and 0.4 kg for weight, a third measurement was taken and the median score was recorded [22].

Table 2.1: Baseline and Change (Δ) Values for Descriptive Variables (N=41)

	Control (N=13)	Soccer (N=11)	Swim (N=17)
Age (y)	11.85 ± 1.28	11.82 ± 1.25	12.24 ± .97
Height (cm)	158.88 ± 7.46	155.69 ± 8.37	157.59 ± 8.18
12 Month Δ	4.14 ± 2.74	5.64 ± 2.27	4.070 ± 2.32
Weight (kg)	51.12 ± 12.55	43.26 ± 5.71	48.84 ± 9.56
12 Month Δ	3.46 ± 2.01	6.25 ± 1.60 [a]	3.65 ± 2.13
Lean Mass (kg)	37.15 ± 6.87	33.99 ± 4.68	37.17 ± 6.13
12 Month Δ	1.84 ± 1.71	4.38 ± 1.41 [b]	3.10 ± 1.45 [c]
Fat Mass (kg)	13.51 ± 6.71 [d]	8.62 ± 2.18	10.75 ± 4.07
12 Month Δ	1.64 ± 1.29	1.64 ± .79	1.26 ± .94

All values reported means ± SD

[a] Soccer higher than both control and swim, $p \leq 0.05$
[b] Soccer higher than control and swim, $p \leq 0.05$
[c] Swim higher than control, $p \leq 0.05$
[d] Control higher than soccer, $p \leq 0.05$

Questionnaires

Tanner Stage ~ As previously validated [5,25], sexual maturation was measured by self-assessment of Tanner breast stage [18]. Each subject was given a handout containing both a picture and a written explanation of Tanner breast stage, and circled the picture that most accurately reflected her developmental appearance. Tanner breast stage was used as a marker for maturation because it is more accurate than pubic hair stages in measuring timing of puberty [34]. Tanner breast stage 2 and 3 are the time when the growth spurt is at maximum velocity, and thus a time for increased bone mineralization of the skeleton. Menarche occurs relatively late in puberty (Tanner Stage 4) and is closely associated with the downward trend of height velocity. Typically girls will gain 6 cm after menarche, but this gain can be doubled. (Table 2.2)

Table 2.2: Change in Tanner Stage from Baseline to Final (N=41)

Baseline – Final Tanner Stage	Control (N=13)	Soccer (N=11)	Swim (N=17)
1-2	0	2 (17%)	1 (6%)
2-2	1 (7%)	0	1 (6%)
2-3	0	3 (25%)	2 (12%)
2-4	1 (7%)	1 (8%)	1 (6%)
3-3	3 (23%)	1 (8%)	2 (12%)
3-4	4 (30%)	3 (25%)	4 (23%)
4-4	3 (23%)	2 (17%)	4 (23%)
4-5	0	0	2 (12%)
5-5	1 (7%)	0	0

Physical Activity ~ The participant filled out a physical activity questionnaire for adolescents [28] with the parent assisting. The questionnaire addressed type and mode, duration, and frequency of the activity. Physical activity is reported for the 12-month observational period.

Soccer Players: The soccer players began participating in the sport at the age of 5.9 ± 1.3 years and had been participating in the sport 6.8 ± 2.0 years. The soccer players trained 2.82 ± 0.9 times per week during the year with training sessions averaging 5-6 hours per week and games were played on the weekend. Eight soccer players participated on basketball teams whose season averaged 13.4 weeks with 2-3 practices per week. Soccer players also participated in softball, swimming, tennis, and track.

Swimmers: The swimmers began participating in the sport at the age 7.8 ± 1.9 years and averaged 5.6 ± 2.1 years of participation in competitive swimming. The swimmers trained 5.9 ± 1.7 sessions per week during the year with training sessions averaging 9-10 hours per week and competitions on the weekend. Four swimmers participated on seasonal soccer teams. They practiced an average of 2.8 times a week with weekly training sessions lasting an average of 4 hours and the soccer season lasted 13.3 weeks. Other weight bearing sports cited were track, gymnastics, jump rope, volleyball, and dance.

Controls: Control subjects were "normally active" and did not participate on a year round sports team, but participated in seasonal sports. Basketball, softball, soccer, and volleyball were most often played. Practices per week averaged 1.7, 4, 2.3, and 3 and the training sessions were 1.7 to 2.7, 4 to 5, 2.3 to 3.3, and 3-4 hours each week, respectively. The length of the season varied between the sports with basketball lasting an 8.7 weeks, softball 9.3 weeks, soccer 11.3 weeks, and volleyball 7.7 weeks. Other weight bearing sports included karate and track.

Nutrition ~ A self administered Block Dietary Kid's Questionnaire was used to determine food intake and nutritional value. The researcher emphasized to both the parent and participant the importance of answering each question in a careful and thoughtful manner. This food frequency questionnaire is designed for kids and adolescents (personal communication). The subjects self reported food intake for the week prior and a hand out was distributed containing portion size pictures. The completed nutrition questionnaires were sent to Block Dietary Data Systems (Berkeley, CA) for analysis. At baseline, dietary calcium intake for the swim group was significantly higher than the soccer and control groups (954.4 ± 333.0 mg vs. 881.1 ± 341.8 mg and 664.9 ± 249.2 mg, respectively). However, after 12-months there was no difference in dietary calcium intake between the control, soccer, and swim groups (727.3 ± 217.1 mg, 910.2 ± 447.0 mg, and 866.6 ± 421.7, respectively). The results reported for our population is less than the recommended 1,300 mg calcium intake for children / adolescents from the National Academy of Sciences and the 1200-1500 mg intake recommended by National Institutes of Health.

Statistical Analysis

Univariate analysis of variance (ANOVA) was used to compare baseline values and 12-month absolute change values between groups for anthropometric variables (height, weight, lean mass, and fat mass) and calcium intake. To assess baseline values for bone variables (BMC and BMD of femoral neck, greater trochanter, total hip, and AP spine) analysis of covariance (ANCOVA) was used (covariates were initial age, height, weight, and Tanner Breast Stage). Analysis of covariance (ANCOVA) was also used to assess absolute change for BMC and BMD at the hip and spine (covariates were initial age, initial BMC or BMD, final Tanner Breast Stage, height change, and weight change). The average age in the development of healthy girls at puberty is 12 years and the range is 10.5 to 15.5 years of age.

Because the timing of puberty is highly individualized, using covariates helps control for growth and reduce the large variability in maturation during the 10 to 14 age spread in our sample. Rationale for using covariates to evaluate BMC and BMD in the adolescent is based on literature demonstrating a strong association between bone accrual and age, height, weight, and Tanner Stage [12,16,17,23]. To verify this association in our data set, we ran Pearson product-moment correlations and observed significant correlations between all bone variables and age, height, weight, and Tanner Breast Stage (range 0.4 – 0.8). All data were analyzed using SPSS version 11.0 (SPSS, Chicago, IL, USA) and data are reported mean (± SD) except for bone data, which are reported as adjusted mean. Significance was set at or below an alpha level 0.05.

Results

Bone Measurements

At baseline, the soccer players had greater trochanter BMC and BMD than controls and the swim group, and femoral neck BMC was significantly greater than swimmers (Table 2.3 and Table 2.4). After 12-months, the soccer players gained significantly more BMC and BMD at the greater trochanter as well as total hip BMD and lumbar spine BMC compared to the swimmers, but not the controls. The control group showed a significantly greater 12-month change for femoral neck and greater trochanter BMC than swimmers. Overall, the swimmers demonstrated a lower accumulation of bone mass than soccer players and swimmers during the 12-month study period.

Table 2.3: Adjusted BMC Baseline Values and Adjusted Change (Δ) Values of Bone Measures. (N = 41)

Bone Variables	Control (N = 13)	Soccer (N = 11)	Swim (N = 17)	Power
WB BMC (g)	1601.8 ± 156.6	1691.0 ± 154.5	1588.0 ± 147.6	.316
12 Month Δ	262.2 ± 70.4 [a]	193.5 ± 78.0	166.9 ± 70.9	.901
FN BMC (g)	3.52 ± .57	4.10 ± .53 [b]	3.43 ± .51	.825
12 Month Δ	.434 ± .216 [c]	.354 ± .249	.240 ± .186	.546
TR BMC (g)	5.75 ± 1.13	6.81 ± 1.12 [d]	5.85 ± 1.07	.553
12 Month Δ	1.23 ± .61 [c]	1.28 ± .67 [b]	.77 ± .60	.559
Hip BMC (g)	24.82 ± 3.54	27.77 ± 3.51	25.15 ± 3.36	.450
12 Month Δ	3.66 ± 1.76	2.76 ± 1.92	2.74 ± 1.74	.240
LS BMC (g)	42.04 ± 6.24	44.18 ± 6.20	41.69 ± 5.92	.138
12 Month Δ	7.12 ± 2.50	8.76 ± 2.72 [b]	6.46 ± 2.48	.437

All values reported adjusted mean ± SD.

WB = whole body; FN = femoral neck; TR = greater trochanter; Hip = total hip; LS = lumbar spine

Baseline means adjusted in analysis of covariance for baseline age, Tanner Stage, weight, and height.

12 Month Δ means adjusted in analysis of covariance for baseline age, baseline BMC, final Tanner Stage, weight change, and height change.

[a] Control greater than soccer and swim, $p \leq 0.05$
[b] Soccer greater than swim, $p \leq 0.05$
[c] Control greater than swim, $p \leq 0.05$
[d] Soccer greater than control and swim, $p \leq 0.05$

Table 2.4: Adjusted BMD Baseline Values and Adjusted Change (Δ) Values of Bone Measures. (N = 41)

Bone Variables	**Control (N = 13)**	**Soccer (N = 11)**	**Swim (N = 17)**	**Power**
FN BMD (g/cm²)	.743 ± .094	.800 ± .093	.746 ± .091	.265
12 Month Δ	.054 ± .029	.058 ± .033	.041 ± .029	.231
TR BMD (g/cm²)	.664 ± .087	.739 ± .086 [a]	.670 ± .082	.501
12 Month Δ	.051 ± .025	.067 ± .027 [b]	.036 ± .025	.709
Hip BMD (g/cm²)	.818 ± .097	.886 ± .096	.828 ± .091	.320
12 Month Δ	.060 ± .029	.069 ± .030 [b]	.043 ± .029	.545
LS BMD (g/cm²)	.812 ± .072	.841 ± .073	.802 ± .070	.210
12 Month Δ	.067 ± .032	.083 ± .036	.056 ± .033	.359

All values reported as adjusted mean ± SD.

FN = femoral neck; TR = greater trochanter; Hip = total hip; LS = lumbar spine

Baseline means adjusted in analysis of covariance for baseline age, Tanner Stage, weight, and height.

12 Month Δ means adjusted in analysis of covariance for baseline age, baseline BMD, final Tanner Stage, weight change, and height change.

[a] Soccer greater than control and swim, $p \leq 0.05$
[b] Soccer greater than swim, $p \leq 0.05$

Discussion

The aim of this study was to examine the influence of loading patterns associated with soccer and swimming on the growing skeleton. Our data support our first hypothesis that differences exist between groups at baseline. We report that, after controlling for growth, soccer players have significantly higher femoral neck BMC and greater trochanter BMC and BMD than swimmers. Our second hypothesis that soccer players would gain more bone mass at the hip and spine compared to controls and swimmers is partially supported. Soccer players accumulated more BMC at the greater trochanter and lumbar spine (40% and 26%, respectively) than the swim group. The 12-month change BMD values at the greater trochanter and total hip were 46% and 38% higher in the soccer players than controls. However, the soccer players and controls were similar at the hip and spine. With respect to our third hypothesis, after 12-months, control subjects gained 45% more BMC at the femoral neck and 38% more at the greater trochanter than the swimmers. There were no differences in bone gains between controls and swimmers at the spine. Thus, our results only partially support out third hypothesis that controls would accrue more bone mass than swimmers at the hip and spine after one year.

Our study has several strengths. First, swimmers and soccer players began their training more than 5 years prior to testing and this allowed us to examine potential differences in bone at baseline between groups prior to our observation period. Second, we examined adolescent athletes prospectively allowing us to evaluate changes over time. Because we studied athletes cross sectionally and then longitudinally, our 12-month change results confirm our observed baseline results that lower bone mass in swimmers is not due to selection bias, but the effect of loading and non-loading on the growing skeleton. Third, we had high subject retainment (41 out of 42) that enrolled in the study and our sample population came from a diverse geographic region. Limitations to this study must also be mentioned. Puberty is a highly individualized process and categorizing by Tanner Stage is not a precise tool for assessing maturation. The average healthy girl takes one year to reach breast stage 3 after the first appearance of the breast bud (Tanner breast stage 2) and 4 years to reach the adult stage, but the range from early puberty to adult can be 1.5 to 5 years or more (Tanner 1989). Thus, a better approach may be to categorize individuals based on age from peak height velocity (PHV) since this method is shown to be a more accurate marker of maturation than Tanner stage. Our sample size was small resulting in low power and requiring a larger effect size for statistical significance. Given the observed lower bone values in swimmers, compared to other groups, we expect higher numbers could strengthen our results. Athletes participated in other weight bearing activities that may have had an additive effect on the skeleton. Further research over longer time with larger populations and more serial measurements is warranted to substantiate our findings.

Our cross sectional results support the notion that reduced weight-bearing is associated with lower bone mass at both the hip and spine compared with higher impact exercise. Previous cross sectional studies on soccer players and controls have examined girls older than our population [1,7,30]. These investigations demonstrate that soccer players have higher BMD at the femoral neck, greater trochanter and lumbar spine than controls. We report no differences between soccer players and controls at the hip and spine. To our knowledge, there are no published data comparing a soccer group to a swim group. We compared our BMD 12-month change values of soccer players to swimmers and found the soccer players added 29% more BMD at the femoral neck, 46% more BMD at the greater trochanter, 38% more BMD at the total hip, and 33% more BMD at the lumbar spine. Also, we report significantly higher greater trochanter and lumbar spine BMC values, which correspond to 40% and 26% more bone mass accrual than swimmers. This occurred despite the higher initial hip and spine BMC and BMD values observed in soccer players.

In a cross sectional study, Courtiex et al.[4] examined 10-year –old gymnasts, swimmers and controls and found that BMC and BMD results of the control and swim groups were similar at the hip and spine. Our baseline data agree with Courtiex et al., but we report 12-month change BMC values in controls at the femoral neck and greater trochanter that are significantly greater than swimmers. Specifically, the control group added 45% more at the femoral neck, 38% more at the greater trochanter, 25% at the total hip, and 9% more at the lumbar spine. Our finding supports the association of increase bone mass at site-specific regions with weight bearing exercise that should increase peak bone mass and potentially reduce the risk of osteoporosis fracture later in life.

We were surprised that soccer and control groups had similar baseline and 12-month change values for hip BMC as we expected soccer players to be higher and gain more bone than controls since soccer training is characterized by running, kicking, quick changes of direction, jumping, bursts of speed, agility that approximate ground reaction forces 3 times body weight [10]. We believe the similarity between our soccer and control subjects and the mixed results between the swim and control groups can be attributed to sports participation, growth, and low sample size. First, the control subjects participated in seasonal sports 8 to 9 months of the year -- soccer, basketball, volleyball and softball, and thus were physically more active than a true "control" group. Second, our data indicate that 62% (8 out of 13) of control subjects, 73% (8 out of 11) soccer players, and 53% (9 out of 17) swimmers were at the beginning or passing through the optimal bone mineral acquisition period (Tanner 2-4) during the 12-months of this study. Two subjects remained at Tanner breast stage 2 and 6 subjects remained at Tanner breast stage 3, and one member from each group passed rapidly through 2 Tanner breast stages, but the majority of subjects passed through only one. This reflects the highly individualized process of sexual maturation. Third, sample size was low reducing statistical power. As for swimming, the horizontal position relied on by swimmers to propel them through water is associated with the non-weight bearing environment of space. It appears that prolonged training in this environment contributes to reduced skeletal accretion at the hip. The discordance in bone mass between soccer players and swimmers may be a direct result in differences in bone loading patterns that influence bone mineralization during growth.

Retrospective studies have explored the association between bone mass accrual and the commencement of sport participation on the attainment of peak bone mass. Haapasalo et al. [11], who studied female squash players, has investigated bone mass of the playing and non-playing arms and also compared players to controls. The playing arm had an increased bone mass and the younger the player started the sport, the greater the side-to-side differences, specifically squash players starting before menarche had side-to-side differences that were 21-24% higher at the humerus than controls. Taaffe et al. [31] reported collegiate female gymnasts began training at 7.5 years of age whereas swimmers began at 12.0 years, while Fehling et al. [8] reported a starting age of 9.9 years and 7.8 years, respectively. The results indicate that gymnasts had greater BMD at the femoral neck by 13% and the lumbar spine by 10% compared to swimmers [8] while gymnasts displayed higher BMD values at the greater trochanter and femoral neck of 17% and 22% [31]. In addition, adolescent swimmers (16.7 years old) reported 6.1 years of specialized training and the results indicated that BMD at the lumbar spine was significantly lower than runners and at the femoral neck BMD was lower than controls, cyclists, runners and triathletes [6]. Furthermore, Heinonen et al. [14] in a 9-month jumping intervention demonstrated higher BMC of the lumbar spine and femoral neck in premenarcheal versus post-menarcheal girls. Our female soccer players' average age of soccer training commencement was 5.9 years and had participated in the sport and average of 6.8 years and our swimmers began at 7.8 years and participated 5.6 years. Thus, it appears that starting age at which kids begin swimming does not have a positive effect on the attainment of peak bone mass, which may be why, over the long term, collegiate swimmers have lower bone mass at the hip. On the other hand, soccer players who have been exposed to mechanical loading prior to menarche or puberty have shown a positive effect on the accrual of peak bone mass at both the hip and spine.

Reports in children and adolescents using intervention programs that incorporate jumping and plyometric exercises have shown site-specific skeletal responses [9,20,38]. In 14-15 year old adolescent girls, Witzke et al. [38] reported significant BMC increases at the greater trochanter of 3.3%, resulting from 30-45 minutes of a plyometric program 3 times per week. Both Morris et al. [24] and MacKelvie et al. [20] utilized school based exercise programs for premenarcheal girls and reported significant BMC gains at the hip and spine. Specifically, femoral neck BMC improved 10.4% and BMD improved 12.0% [24] and femoral neck BMC improved 5% with lumbar spine BMC improving 4% [20]. The jumping program by Fuchs et al. [9] in pre-pubertal kids reported in ground reaction forces 8-9 times body weight, which resulted in a 9% improvement for femoral neck BMC and a 10% improvement at the lumbar spine. Thus, applying various mechanical strains upon the growing skeletal demonstrates site-specific adaptations at the hip and spine and corresponds to our data in soccer players and control subjects.

Our data provide preliminary support for the hypothesis that mechanical loading patterns during growth may have long term skeletal consequences. We emphasize that loading patterns associated with soccer training have a positive impact on peak bone mass at the hip and spine, especially when started prior to puberty. The 12-month BMC change value at the spine was 26% higher in the soccer players than the swimmers. Furthermore, the greater trochanter 12-month BMC change was 40% higher in the soccer players than swimmers and femoral neck BMC 12-month gain was 43% higher in controls than swimmers despite the fact that they had higher initial trochanteric bone mass. While we recognize that swimming has positive effects on strength and cardiovascular fitness, year round competition may compromise bone gains during growth and result in lower peak bone mass. In addition, adding a weight bearing impact loading to a swimmer's training routine may be warranted and the practicality should be investigated since intervention programs that incorporated jumping and plyometrics have shown positive results at the hip and spine in children and adolescents [9,20,21,38].

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Chapter 3

BONE GAINS IN ADOLESCENT MALE ATHLETES AND NON-ATHLETES

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Abstract

Discordance in bone mass between young adult swimmers and soccer players may be a direct result of differences in bone loading patterns that influence bone mineralization during growth. Our aim in this study was to evaluate whether sports participation (soccer and swimming) had an independent effect on bone mass accrual at the hip and lumbar spine. We recruited boys 10 to 14-years of age were from Corvallis, Albany, Salem, Bend and the greater Portland area. Bone mineral content (BMC, g) and bone mineral density (BMD, g/cm^2) of the proximal left hip, spine (AP), and whole body as well as lean mass and fat mass were assessed by dual energy x-ray absorpiometry (Hologic QDR 4500A; Hologic Inc., Waltham, MA, USA). Using ANCOVA, (covariates: initial age, height, weight, and Tanner Stage), at baseline, all groups were similar at the hip and spine. After one year, ANCOVA was also used to assess absolute change for BMC and BMD at the hip and spine (covariates: initial age, initial BMC or BMD, final Tanner Stage, height change, and weight change). Soccer players had a significantly higher 12-month change for femoral neck BMC than swimmers, but were similar at the spine. There were no differences between the control subjects and the swimmers for 12-month change values the hip and spine. At baseline and after 12-months, the control group had significantly more fat mass than the soccer players and swimmers. While preliminary and limited by the small sample size, our results indicate that after controlling for growth, the soccer players gained significantly more BMC at the femoral neck than swimmers. Our results indicate that exposing the young skeleton to impact loading exercise has site-specific benefits at the hip whereas prolonged training in a non-weight bearing environment may compromise skeletal acquisition. Furthermore, vigorous physical activity associated with soccer and swim training lead to an increase in fat free mass and a decrease in fat mass, thus reducing the risk of obesity, cardiovascular disease, and type 2 diabetes.

Introduction

Osteoporosis is a disease characterized by low bone mass and structural deterioration of bone tissue, leading to increased fragility, and susceptibility to fracture [1]. Of the 10 million people in the United States that have osteoporosis, 2 million are men (20%). There are over 300,000 hip and 700,000 vertebral fractures annually in the United States and the associated expenditure exceeds 17 billion dollars annually [2]. While osteoporosis is often considered a disease of aging, lifestyle choices during growth may offset the development of osteoporosis by improving peak bone mass, the maximum amount of bone mass attained in the young adult skeleton. Since 60-80% of peak bone mass is genetically determined, up to 40% may be altered by lifestyle. Thus, exercise patterns that load the skeleton before and during puberty contribute to peak bone mass accrual [3,4,5] and the increase in peak bone mass may reduce the risk of osteoporotic fractures later in life [6].

Physical activity, specifically impact exercise, is associated with higher peak bone mass [7,8,9]. Both cross sectional and retrospective studies have compared young female athletes who participate in sports with different impact loading patterns to nonathletic controls [10,11]. Fehling et al. [12] showed that bone mineral density (BMD) of the femoral neck (hip) and lumbar spine were greatest in collegiate gymnasts and volleyball players but that swimmers and controls showed no difference between BMD of the femoral neck and lumbar spine. Data from our laboratory demonstrate that collegiate female swimmers have lower hip bone mass than both gymnasts and controls [9]. Although swimmers are strong powerful athletes, active loading associated with swimming may not be enough to offset the non-weight bearing effect of the buoyant water environment. Studies of soccer players further confirm the hypothesis that impact activity is osteogenic. Söderman et al. [13] showed that hip BMD of high school aged female soccer players was 14.8% to 16.5% higher than controls, while Alfredson et al. [14] reported higher spine BMD (4.8%) in collegiate soccer players versus controls. This discordance in bone mass between swimmers, gymnasts, and controls may be a direct result of differences in bone loading patterns that influence bone mineralization during growth.

The limited published data in male athletes is a result of cross sectional studies [15,16] and three studies have examined mountain or road cyclists [17,18,19]. To our knowledge, only three studies have been published using male soccer players [20,21,22] and one study on male swimmers [23] that have examined loading patterns and the association of bone mineral accrual at the hip and spine. Furthermore, the age of the subject population in these studies have been adults in their early 20's, middle 30's or mid 50's. Thus, little is known about male athletes and how loading patterns influence bone mineral accrual during growth.

In this study, our aim was to evaluate whether sports participation (soccer and swimming) had an independent effect on bone mass accrual at the hip and lumbar spine. We studied young athletes and controls at baseline and over 12-months and asked the following research questions: 1) At baseline, are there differences in bone mass between adolescent soccer players, swimmers, and control subjects? 2) Over 1 year, is bone mass accrual greater in soccer players than in swimmers and controls? and 3) Over one year, is bone mass accrual in control subjects greater than in swimmers? Based on the literature we hypothesized the following: 1) at baseline there would be differences in body size and bone mass between groups; 2) soccer players would have greater bone mass accrual at the hip and spine than control subjects and swimmers; and 3) there would be no difference in bone mass accrual at the hip and spine between controls and swimmers. If soccer players gain more bone mass and swimmers gain less bone mass, then we can develop a simple impact exercise program for swimmers to include during warm-up activities that may contribute to improved bone acquisition at this critical time in growth.

Materials and Methods

Participants

Boys 10 to 14-years of age were recruited from Corvallis, Albany, Salem, Bend and the greater Portland area. For inclusion, participants met the following criteria: 1) member of a year-round swimming team, member of a year-round soccer club, or active but not participating in any year round sport; 2) in grades 6 through 8; 3) a non-smoker; 4) not taking medications that affect bone metabolism; 5) able and willing to participate for 12 months; and 6) free of metabolic and/or respiratory disease and orthopedic problems. Thus, thirty-six boys were enrolled into the study and placed into one of three groups: 1) control; 2) soccer; and 3) swim. The Oregon State University Institutional Review Board and the Oregon State Board of Radiology approved the research protocol. Both the parent and the subject gave written informed consent to participate before entry into the study.

Four subjects did not return for their follow-up testing one-year later; one subject moved (control), 2 subjects quit the sport (swimming), and 1 subject continuously missed his appointments (control). Thirty-two subjects (11 controls, 13 soccer players, and 8 swimmers) completed the longitudinal study. Of these, 30 were white, 1 African American, and 1 Black of Caribbean descent.

Bone Measurements

Bone mineral content (BMC, g) and bone mineral density (BMD, g/cm^2) of the proximal left hip, spine (AP), and whole body were assessed by dual energy x-ray absorpiometry (Hologic QDR 4500A; Hologic Inc., Waltham, MA, USA). We report BMC values because bone mass and area do not increase proportionally during growth [24], and we provide BMD data since the majority of studies report BMD values although we acknowledge that changes in proportion of cortical and trabecular bone (size and thickness) that occur during growth affect BMD measurement [25]. Because bone accretion varies regionally in the growing skeleton [24], whole body scans were employed to detect change in overall bone mass. All scans were performed in fast array mode and analyzed using Hologic QDR Software for Windows 98 (ver 11.2). To maintain the hip in 30 degrees of internal rotation, a positional device was used. Lumbar spine scans were performed with the subject on his/her back with a foam block placed under the legs to maintain 90 degrees of flexion at the hips and knees and decrease the lordotic curve of the lumbar spine. A licensed radiologic technician performed all scans.

Anthropometric Measurements

Height and weight were measured without shoes in exercise clothing (shorts, t-shirt, and/or sweat suit). Height was measured to the nearest mm using a wall-mounted stadiometer (Seca Model S-220; Hanover, MD, USA) and weight was measured to the nearest 0.1 kg (Seca Alpha Model #770). Two measurements were taken for each anthropometric variable and averaged. If a measure was greater than 4 mm for height and 0.4 kg for weight, a third measurement was taken and the median score was recorded [26]. Anthropometric measurements are summarized in Table 3.1.

Questionnaires

Tanner Stage ~ Pubertal development was categorized by self-assessment of Tanner Stage [27], which has been previously validated [28,29]. A handout containing both a picture and a written explanation were given to each subject, and the subject circled the picture that most accurately reflected his developmental appearance. Sexual maturation data (Tanner Stage) are summarized in Table 3.1. Peak height velocity is not the first sign of puberty in boys, but testicular enlargement followed by penis growth then the appearance of pubic hair and this timing is highly variable [30]. For example, the average age for the beginning of penis growth is 12.5 years, but one can begin as early as 10.5 years or as late as 14.5. Conversely, the completion of penis growth is approximately 14.5 years, but can be as early as 12.5 years or as late as 16.5 years. Thus, those who mature earlier will have completed this phase of sexual maturation while some boys will just be beginning this phase of sexual development.

Physical Activity ~ Each participant completed a physical activity questionnaire for adolescents [31] with the parent assisting. The questionnaire addressed mode, duration, and frequency of the activity. Physical activity is reported for the 12-month observational period.

Soccer Players: The soccer players began participating in the sport at the age of 5.3 ± 1.1 years and had been participating in the sport 9.0 ± 1.8 years. The soccer players trained 3.15 ± 0.9 times per week during the year with training sessions averaging 8-9 hours per week and games on the weekend. Soccer players also participated in basketball (4), wrestling, golf, and baseball (2).

Table 3.1: Change in Tanner Stage from Baseline to Final (N=32)

Baseline - Final Tanner Stage	**Control (N=11)**	**Soccer (N=13)**	**Swim (N=8)**
1-1	18% (2)	7% (1)	12% (1)
1-2	9% (1)	0	0
1-3	9% (1)	7% (1)	0
2-2	9% (1)	0	12% (1)
2-3	9% (1)	0	40% (3)
2-4	0	15% (2)	12% (1)
3-3	9% (1)	15% (2)	0
3-4	18% (2)	15% (2)	12% (1)
4-4	9% (1)	7% (1)	0
4-5	9% (1)	30% (4)	12% (1)

<u>Swimmers</u>: The swimmers began participating at the age of 7.5 ± 2.1 years and averaged 5.5 ± 2.4 years of participation in competitive swimming. The swimmers trained 5.6 ± 1.8 sessions per week during the year with training sessions averaging 10-11 hours per week. Competitions were held on weekend.

<u>Controls</u>: Control subjects did not participate on a year round sport team, but were "normally active" and participated in seasonal sports. Seven control subjects participated in basketball, which practiced 3.0 times per week and trained 3-4 hours a week. The season lasted an average of 14.8 weeks. Baseball and soccer were other popular sports (9 and 6 subjects, respectively). Baseball practiced 3.4 times a week and trained 2.4 to 4.4 hours per week, while soccer practiced 2 times a week and trained 2-3 hours each week. The length of the season varied between the sports with basketball lasting 14.8 weeks, baseball 12.5 weeks, and soccer 12.7 weeks. Other sports the control subjects participated in were football (2), hockey (2), and track.

Nutrition ~ A self administered Block Dietary Kid's Questionnaire was used to determine food intake and nutritional value. The researcher emphasized to both the parent and participant the importance of answering each question in a careful and thoughtful manner. This food frequency questionnaire is designed for kids and adolescents (personal communication). The subjects self reported food intake for the week prior and a hand out was distributed containing portion size pictures. The completed nutrition questionnaires were sent to Block Dietary Data Systems (Berkeley, CA) for analysis. Due to severe errors (too few food items consumed), 28 out of 32 dietary questionnaires were used for the analysis. Based on the nutrient information obtained from the Block Dietary Kid's questionnaire, calcium intake was similar for all groups at baseline (control 844.0 ± 284.1 mg, 912.5 ± 429.2 mg, and 779.4 ± 325.8 mg) and at 12-months (control 1005.8 ± 516.7 mg, soccer 853.4 ± 493.6 mg, and swim 958.2 ± 364.9). The results reported for our population is less than the recommended 1,300 mg calcium intake for children / adolescents from the National

Academy of Sciences and the 1200-1500 mg intake recommended by National Institutes of Health.

Statistical Analysis

Univariate analysis of variance (ANOVA) was used to compare baseline values and 12-month absolute change between groups for anthropometric variables (height, weight, lean mass and fat mass) and calcium intake. Baseline BMC and BMD values of femoral neck, greater trochanter, total hip, and AP spine) analysis of covariance (ANCOVA) was used (covariates were initial age, height, weight, and Tanner Stage). Analysis of covariance (ANCOVA) was also used to assess absolute change for BMC and BMD at the hip and spine (covariates were initial age, initial BMC or BMD, final Tanner Stage, height change, and weight change). The average age in the development of health boys at puberty is 14 years and the range is 10.5 to 16.5 years of age. Because the timing of puberty is highly individualized, using covariates helps control for growth and reduce the variablility in maturation during this time period. Rationale for using covariates to evaluate BMC and BMD in the adolescent is based on literature demonstrating a strong association between bone accrual and age, height, weight, and Tanner Stage [32,33,34,35]. To verify this association in our data set, we ran Pearson product-moment correlations and observed moderate to strong correlations between all bone variables and age, height, weight, and Tanner Stage (range 0.5 –0.9). All data were analyzed using SPSS version 11.0 (SPSS, Chicago, IL, USA) and data are reported mean (± SD) except for bone data, which is reported as adjusted mean (Table 3.3 and Table 3.4). Significance was set at or below an alpha level 0.05.

Results

Subject Characteristics

Baseline data and 12-month change in body size are presented in Table 3.2. At baseline, the soccer players were significantly older than the control subjects, but not the swimmers. Also, the soccer players were significantly taller than the swimmers. Both the control subjects and soccer players were significantly heavier than the swimmers. After 12 months, all groups were similar for change in height and weight.

Bone Measurements

At baseline, all groups were similar at the hip and spine. After one year, the soccer players had a significantly higher 12-month change for femoral neck BMC than swimmers, but were similar at the spine. There were no differences between the control subjects and the swimmers for 12-month change values the hip and spine. (Table 3.3 and Table 3.4)

Table 3.2: Baseline and Change (Δ) Values for Descriptive Variables (N=32)

	Control (N=11)	**Soccer (N=13)**	**Swim (N=8)**
Age (y)	11.73 ± 1.27	12.92 ± 1.26 [a]	11.88 ± .84
Height (cm)	155.31 ± 13.73	162.61 ± 9.76 [b]	151.77 ± 6.00
12 Month Δ	6.46 ± 2.48	5.80 ± 2.57	7.15 ± 1.47
Weight (kg)	49.54 ± 11.84 [c]	49.34 ± 10.15 [b]	40.14 ± 4.45
12 Month Δ	6.20 ± 2.49	5.86 ± 3.61	5.50 ± 2.69
Lean Mass (kg)	37.94 ± 92.55	41.95 ± 96.67 [b]	33.07 ± 41.52
12 Month Δ	4.17 ± 3.39	5.34 ± 3.24	5.06 ± 2.27
Fat Mass (kg)	11.10 ± 5.31 [c]	6.24 ± 1.34	6.35 ± 6.60
12 Month Δ	2.07 ± 2.30 [d]	1.07 ± 1.02	.584 ± .45

All values reported means ± SD.

[a] Soccer higher than control, $p \leq 0.05$
[b] Soccer higher than swim, $p \leq 0.05$
[c] Control higher than both soccer and swim, $p \leq 0.05$
[d] Control higher than swim, $p \leq 0.05$

Table 3.3: Adjusted BMC Baseline Values and Adjusted Change (D) Values of Bone Measures (N=32).

Bone Variables	**Control (N = 11)**	**Soccer (N = 13)**	**Swim (N = 8)**	**Power ***
WB BMC (g)	1577.3 ± 210.6	1675.1 ± 196.4	1644.7 ± 185.9	0.132
12 Month Δ	333.2 ± 92.1 [a]	272.7 ± 91.6	201.8 ± 88.1	0.743
FN BMC (g)	3.99 ± .51	3.93 ± .48	3.74 ± .45	0.15
12 Month Δ	.460 ± .285	.500 ± .281 [b]	.237 ± .277	0.42
TR BMC (g)	6.87 ± 1.58	7.22 ± 1.48	6.55 ± 1.39	0.131
12 Month Δ	1.503± .8	1.53 ± .76	1.09 ± .76	0.193
Hip BMC (g)	26.69 ± 4.73	29.25 ± 4.41	27.89 ± 4.18	0.166
12 Month Δ	4.32 ± 2.8	5.79 ± 2.82	4.46 ± 2.73	0.182
LS BMC (g)	36.43 ± 9.64	41.64 ± 8.99	39.28 ± 8.5	0.163
12 Month Δ	8.55 ± 2.7	8.29 ± 2.74	6.57 ± 2.64	0.279

All values reported adjusted means ± SD.

WB = whole body; FN = femoral neck; TR = greater Trochanter; Hip = total hip; LS = lumbar spine

Baseline means adjusted in analysis of covariance for initial age, initial Tanner Stage, initial weight, and initial height.

12-Month Δ means adjusted in analysis of covariance for initial age, initial BMC , final Tanner Stage, weight change, and height change.

[a] Control greater than swim, $p \leq 0.05$
[b] Soccer greater than swim, $p \leq 0.05$

Table 3.4: Adjusted BMD Baseline Values and Adjusted Change (Δ) Values of Bone Measures (N=32).

Bone Variables	**Control (N = 11)**	**Soccer (N = 13)**	**Swim (N = 8)**	**Power ***
FN BMD (g/cm^2)	.810 ± .099	.798 ± .094	.762 ± .088	0.15
12 Month Δ	.057 ± .040	.055 ± .040	.042 ± .040	0.108
TR BMD (g/cm^2)	.705 ± .106	.727 ± .097	.672 ± .093	0.178
12 Month Δ	.060 ± .030	.053 ± .029	.044 ± .028	0.141
Hip BMD (g/cm^2)	.859 ± .113	.871 ± .105	.825 ± .099	0.128
12 Month Δ	.066 ± .033	.066 ± .032	.051 ± .031	0.15
LS BMD (g/cm^2)	.702 ± .123	.770 ± .115	.757 ± .107	0.174
12 Month Δ	.077 ± .040	.075 ± .040	.048 ± .037	0.316

All values reported adjusted means ± SD.

FN = femoral neck; TR = greater Trochanter; Hip = total hip; LS = lumbar spine

Baseline means adjusted in analysis of covariance for initial age, initial Tanner Stage, initial weight, and initial height.

12 Month Δ means adjusted in analysis of covariance for initial age, initial BMD, final Tanner Stage, weight change, and height change.

No differences between groups.

Discussion

The aim of this study was to examine the influence of loading patterns associated with soccer and swimming during the adolescent growth spurt. We report no differences between groups at baseline and this result does not support our first hypothesis. After one year, soccer players and control subjects were similar at the hip and spine, but soccer players had a significantly greater 12-month change of BMC at the femoral neck than swimmers. More important, even after controlling for growth, the 12-month change value at the femoral neck was 2 times that gained of the swimmers despite the fact that soccer players had higher initial BMC at the hip. This result supports our hypothesis that soccer players have more bone mass accrual at the hip. However, our data does not support the hypothesis that soccer players will have a greater bone mass accrual at the spine compared to controls and swimmers. We report no differences between control subjects and swimmers for 12-month change values at the hip and spine. Hence, our data does support our third hypothesis that controls subjects and swimmers would be similar in bone mass accrual at the hip.

Our study has several strengths. First, there are few prospective reports of growth in boys, and, to our knowledge, none comparing mechanical loading patterns. Second, swimmers and soccer players began their training more than 5 years prior to testing and this allowed us to examine potential differences in bone at baseline between groups prior to our observation period. Third, we examined adolescent athletes prospectively allowing us to evaluate changes over time. Fourth, we retained 32 out of 36 subjects who enrolled in the study and our sample population came from a diverse geographic region. Fifth, our swimmers competed at the regional and state level, and one swimmer is ranked nationally. The soccer players were on a team that competed at the premier level and were state cup runner-up in their age bracket in 2003. Limitations to this study must also be mentioned. Thus, we cannot eliminate the possibility of selection bias or draw cause-and-effect conclusions. Puberty is a highly individualized process and categorizing by Tanner Stage is not a precise tool for assessing maturation. The average healthy boy takes one year to reach Tanner stage 3 after the first enlargement of the testicle (Tanner 2) and 3 years to reach the adult stage (Tanner 5), but some boys take only 2 years [30]. Thus, a better approach may be to categorize individuals based on age from peak height velocity (PHV) since this method is shown to be a more accurate marker of maturation than Tanner stage. Our sample population was low reducing statistical power. Further research is warranted with larger populations and longer observational periods to substantiate our findings.

To our knowledge, there are no published data comparing soccer players to swimmers. At baseline, after controlling for growth, BMC and BMD at the hip and spine were not different between groups. However, 12-month change scores were different at the hip in soccer players. We report a significant gain in soccer players at the femoral neck than swimmers and greater gains at the hip and spine. Specifically, for the 12-month BMC change the soccer players had 53% more BMC at the femoral neck and 29%, 23%, and 21% more at the greater trochanter, total hip, and lumbar spine respectively.

Previous cross sectional studies [20,21,22] have examined male soccer players at various levels of competition. Karlsson et al. [21] and Magnusson et al. [22], in different studies but using the same male soccer players, reported femoral neck and greater trochanter BMD 13% and 15% higher than control subjects. The average age of the subjects was 22.7 years and the range was 17-35 years. Calbert et al. [20] reported BMC and BMD of soccer players (average age 23 years) were significantly higher at the femoral neck (24% and 21%), greater trochanter (23% and 21%), and the lumbar spine (10% and 13%). Our data indicate that in developing boys, soccer players and controls have similar bone mass at the hip and spine. Also, Taaffe et al. [23] examined collegiate male swimmers and reported no differences in BMD values at the hip and spine compared to a control group. Although 12-month BMC change values in controls and swimmers were not significantly different at the hip and spine, the values were higher for the controls. Specifically, the control subjects had 48% more BMC at the femoral neck, 28% more at the greater trochanter, and 23% more at the femoral neck, and 23% more at the lumbar spine.

The running of soccer is associated with ground reaction forces of 3 times body weight [8]. Also, the plant leg when kicking a soccer ball compresses the femoral neck into the acetabulum and the gluteus muscles contracting provide stability at the hip that mechanically loads the skeleton. We expected the soccer players to have higher hip and spine bone mass at baseline and accrue more bone mass over 12-months, but after examining physical activity we were not surprised by our null findings. We believe the similarity in bone between the soccer group and control group as well as the higher 12-month change values seen in the control subjects can be attributed to sports participation, growth, and sample size. First, the control subjects participated in seasonal sports-- soccer, basketball, and baseball, which are played at different times of the year. By participating in various sports, the control subjects were mechanically loading their skeletons 8 to 9 months of the year. Second, our data indicate that 36% (4 out of 11) of control subjects, 46% (6 out of 13) soccer players, and 62% (5 out of 8) swimmers were at the beginning or passing through the growth spurt (Tanner stage 2 or 3) during the 12-months of this study. Two subjects remained at Tanner stage 2 and 3 subjects remained at Tanner stage 3, plus 1 membereach from the control and swim groups and 3 from the soccer group passed rapidly through 2 Tanner stages, but the majority of subjects passed through only one. This reflects the highly individualized process of sexual maturation. Third, our sample size was low reducing statistical power. As for swimmers, the buoyancy of the water creates a non-weight bearing environment that does not benefit the skeleton at the hip. This discordance in bone mass between the soccer players and swimmers may be a direct result of the exercise loading patterns that influence bone mineralization during growth.

A retrospective study by Calbert et al. [20] explored bone mass accrual, the commencement of sport participation, and the attainment of peak bone mass and found soccer players that began participating before puberty (12 years) showed higher bone mass at the hip and spine when compared to controls. Furthermore, Bradney et al. [26] in an 8-month exercise program of pre-pubertal boys demonstrated an increase in bone mass at the spine and Sundberg et al. [37] showed a greater femoral neck bone mass in peri-pubertal boys who increased their exercise levels within a school physical education class. In the current study, average starting age of soccer training was 5.3 years and they had participated in the sport an average of 9.0 years and our swimmers began at 7.5 and participated 5.5 years. Thus, it appears that starting age at which kids begin swimming does not have a positive effect on the attainment of peak bone mass, which may be why, over the long term, collegiate swimmers have lower bone mass at the hip. The soccer players have been exposed to hours of mechanical loading prior to puberty and this should help in the attainment of peak bone mass.

Although not a primary aim of our study, we found that sports participation had a positive effect on body composition. At baseline, soccer players had a significantly greater lean mass than to swimmers and controls had a significantly higher fat mass than both the soccer players and swimmers. After one year, control subjects gained 72% more fat mass than swimmers. According to Gutin et al. [38], excess fatness (obesity) in children is associated with several metabolic problems: insulin resistance (hyperinsulinemia), unbalanced ratio of total cholesterol to HDL cholesterol (dyslipidemia), and elevated blood pressure. Thus, early in life, pathological metabolic disorders have begun, affecting the health of our youth, leading to the increased risk of cardiovascular disease and type 2 diabetes diseases. However, a paradigm has been presented by Gutin et al. [38] that indicates increased vigorous physical activity leads to increased protein turnover/synthesis, which leads to increased fat free mass leading to decreased fatness that leads to increased fitness. Thus, even if swimming may be associated with reduced bone mass, it does have positive effects on body composition.

While preliminary and limited by the small sample size, our results indicate that, after controlling for growth, the soccer players gained more BMC at the femoral neck than swimmers. Our results indicate that exposing the growing skeleton to impact loading has site-specific benefits whereas prolonged training in a non-weight bearing environment may compromise skeletal acquisition. Thus, the growing skeleton that is subjected to various mechanical loading patterns may result in greater bone mineral accrual during these critical years of growth and thus increase peak bone mass. Both soccer players and swimmers had greater lean mass and lower fat mass than swimmers, but the vigorous physical training of swimming resulted in less fat mass accumulation and thus further decreasing the risk of type 2 diabetes, obesity, and cardiovascular disease—major health problem in the United States.

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Conclusions

As more and more people lead sedentary lifestyles, vigorous physical activity, eating a nutritious diet, and following healthy habits as a child becomes apparent by the increased prevalence of osteoporosis, obesity, and type 2 diabetes. Osteoporosis is a disease, whose diagnosis is made by measuring BMD at the hip and spine, that can be effectively retarded or prevented later in life by adding bone mass during youth and maintaining levels through adulthood. Peak bone mass is attained by mechanically loading the skeleton with weight bearing exercise. Cross sectional studies show an association of increased bone mass at the hip and spine with impact sports such as gymnastics, volleyball, and soccer. In addition, randomized, controlled studies on pre-pubescent boys and girls clearly demonstrate the positive benefit of jumping and its causal effect of increasing peak bone mass in school based programs. Our study of adolescent boys and girls allowed us to compare soccer players, swimmers, and controls at baseline to determine if differences existed at the hip and spine then determine the influence of soccer and swim training on the attainment of bone mass during the growth spurt.

Boys and girls were analyzed separately due to known differences during puberty. We controlled for growth and at baseline there were no differences at the hip and spine between the boy soccer players, swimmers, and controls. We had expected soccer players to have higher bone mass due to the vigorous nature that soccer training entails, but analysis of the physical activity questionnaire revealed that our control subjects participated on seasonal sport teams and thus were not "normal controls". At 12-months, the soccer players gained significantly more BMC at the femoral neck than swimmers. Specifically, soccer players gained two times the amount of BMC compared to the swimmers 12-month value. No other differences were evident at 12 months and overall the swimmers had lower values than both the soccer players and controls.

As for the girls, at baseline soccer players had higher BMC and BMD at the greater trochanter than both the controls and the swimmers and higher femoral neck BMC than swimmers. At 12-months, the soccer players gained more BMC at the greater trochanter and lumbar spine and gained more BMD at the greater trochanter and total hip. The control subjects gained more BMC at the femoral neck and greater trochanter than swimmers. Even after controlling for growth, the soccer players and controls added 40% and 38% more greater trochanter BMC than swimmers.

A major strength of the study was the prospective nature that allowed us to follow our subjects and measure bone mass gains during the growth spurt. Also, both the boy and girl athletes began their sports participation prior to puberty and thus we were able to determine an association of specific sports training and the influence on bone mass gains. Limitations also must be mentioned. Our low sample size leads to reduced statistical power and decreases the chance of finding significance. Both the boys and girls swimmers had lower bone mass scores than the soccer players and we believe with more subjects statistically significant differences would become evident between the groups.

Even though swimmers began participating in their sport 2 years later than soccer players, we report discordance in bone mass between soccer players, controls and swimmers, which may be a direct result of different loading patterns that influence bone mineralization during the growth spurt. Our results indicate that exposing the young skeleton to impact exercise has site-specific benefits at the hip and spine whereas prolonged training in a non-weight bearing environment may compromise skeletal integrity. Furthermore, we suggest implementing impact exercise into a swimmer's training routine, which may stimulate bone gains at the hip and spine.

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APPENDICIES

APPENDIX A: Institutional Review Board Approval

COPY

OREGON STATE UNIVERSITY

Report of Review by the Institutional Review Board for the Protection of Human Subjects

TO: Christine Snow, ExSS

COPY: Todd Rinder, ExSS

RE: Exercise to increase bone mass and reduce shoulder injuries in adolescent swimmers

The referenced project was reviewed under the guidelines of Oregon State University's institutional review board (IRB), the Committee for the Protection of Human Subjects, and the U.S. Department of Health and Human Services. The IRB has **approved** your application. The approval of this application expires upon the completion of the project or one year from the approval date, whichever is sooner. The informed consent form obtained from each subject should be retained in program/project's files for three years beyond the end date of the project.

Any proposed change to the protocol or informed consent form that is not included in the approved application must be submitted to the IRB for review and must be approved by the committee before it can be implemented. Immediate action may be taken where necessary to eliminate apparent hazards to subjects, but this modification to the approved project must be reported immediately to the IRB.

[signature] Date: 12/18/00

Warren N. Suzuki, Chair
Committee for the Protection of Human Subjects
(Education, 7-6393, suzukiw@orst.edu)

APPENDIX B: Institutional Review Board Modification

Report of Review by the Institutional Review Board for the
Protection of Human Subjects

November 2, 2001

TO: Christine Snow
EXSS

COPY: Laura Lincoln
Research Office

RE: Evaluation of Bone Mass and Shoulder Injuries in Adolescent Swim

The referenced proposed modification to a previously approved project was reviewed under the guidelines of Oregon State University's institutional review board (IRB), the Committee for the Protection of Human Subjects, and the U.S. Department of Health and Human Services. The IRB has **approved** the modification.

Any additional change to the protocol or informed consent form that is not included in the approved application as modified must be submitted to the IRB for review and must be approved by the committee before it can be implemented. Immediate action may be taken where necessary to eliminate an apparent hazard to subjects, and any actual harm or potential risk not previously known by the IRB, must be reported immediately to the IRB.

_______________________________ Date: __________
Institutional Review Board

APPENDIX C: Informed Consent

INFORMED CONSENT

Title: Bone Gains in Adolescent Athletes and Nonathletes

Researchers:

Principal Investigator	Christine Snow, PhD	737-6788
Research Associate	Todd Rinder	737-6794

Background and Purpose:

The amount of bone gained during growth is a primary risk factor for osteoporosis. Therefore, increasing bone during growth may decrease fractures later in life. Studies of_collegiate soccer players support the hypothesis that weight-bearing activity increases bone mass, whereas collegiate swimmers (non-weight bearing) have lower bone mass of the hip and spine than non-swimmers, college gymnasts and college soccer players. However, it is not known whether young swimmers have lower than normal bone mass changes during growth. If so, programs could be planned to improve bone health. Furthermore, soccer's training regime may be a greater benefit for the attainment of peak bone mass than just growth alone. In this project we plan to evaluate bone mass and compare young swimmers, soccer players, and nonathletes.

Procedures:

I have been invited by Dr. Christine Snow to participate in this study that will evaluate sports participation on bone mineral density. I am a healthy adolescent, and either a swimmer, soccer player or active, but do not participate in organized sport. I am a non-smoker, not taking medications that affect bone metabolism, able to participate for 1 year, and do not have diabetes and/or respiratory disease or orthopedic problems. All testing will take place at Oregon State University's Bone Research Laboratory. I agree to the following:

Tests and Questionnaires to be completed at the beginning and end of study

<u>Bone Mineral Density (BMD) Testing:</u>

A bone scanner will measure BMD of my hip, spine, and whole body. The technique provides an accurate measure of bone density with a very low exposure to radiation and is considered safe to administer on several occasions. Time for the procedure is no more than 20 minutes. I have not had a nuclear medicine procedure or x-ray scan using contrast agents within the past week and did not take a calcium supplement the day of testing.

<u>Questionnaires:</u>

I will complete the following questionnaires:

1) Health History

2) Exercise/Physical Activity—I will complete a questionnaire that will ask questions about the types of activities I participate on a regular basis. Also, questions will be asked regarding the amount of TV watched and the types of

organized sports in which I am involved. My mom or dad may assist me with filling out the questionnaire.

3) Nutritional Questionnaire—I will record my food intake on a questionnaire that takes approximately 20 minutes to complete. It will require that I answer questions based on the types of food I eat on a regular basis throughout the year. My mom or dad may assist me with filling out the questionnaire.

4) Tanner Staging—measures my stage of development. In girls this will involve evaluating breast and pubic hair and in boys this will involve evaluating only pubic hair. A detailed description and a picture of each stage is provided on the questionnaire. A researcher of the same sex will hand this questionnaire to me.

Potential Risks and Benefits:

By participating in this study, I will receive important information regarding bone mineral density, body composition, and dietary (nutrient) intake. The assessments and evaluations are not diagnostic and any questions regarding my outcomes should be directed to my doctor. Exposure to radiation is very low from the bone scanner and the amount of radiation I will receive is equivalent to the amount that I would receive in one day from natural background radiation. I understand that OSU does not provide a research subject with compensation or medical treatment in the event a participant is injured, or as a result of participation in the research project.

Confidentiality:

Any information obtained in connection with this study that can be identified by me will be kept confidential by the extent permitted by law. A code number will be used to identify any test or other information I provide. Neither my name nor any information from which I might be identified will be used in any data summaries or publication.

Voluntary Participation Statement:

I understand that participation is voluntary and I may stop a test if it is uncomfortable to me. I may withdraw / discontinue participation in this study at any time without sacrificing any benefits to which I am entitled.

If I have Questions:

I understand that any questions I have about the research study and/or specific procedures should be directed to Christine Snow at 737-6788, 106 Women's Building, Oregon State University or Todd Rinder at 737-6794, 121D Langton Hall, Oregon State University. If I have questions about my rights as a research subject I should contact the IRB Coordinator at 737-3437, OSU Research Office.

My signature below indicates that I have read and understand the procedures described above and give my informed and voluntary consent to participate in this study. I will receive a signed copy of this consent form.

Signature of Participant Date

Signature of Parent Date

Signature of Principal Investigator Date

APPENDIX D: Health History Questionnaire

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY

HEALTH HISTORY QUESTIONNAIRE

Last name First Middle Male Female

Address Home phone

City State Zip Team name

Weight (kg) Height (cm) Date of birth Age

Which describes your racial/ethnic identify? (Please check all that apply)

- ❑ White, European American, Non-Hispanic
- ❑ North African or North African-American
- ❑ Asian, Asian American
- ❑ Pacific Islander
- ❑ Black, African American, Non-Hispanic
- ❑ Hispanic of Latino American
- ❑ Middle Eastern or Middle-Eastern American
- ❑ American Indian or Alaskan Native
- ❑ Decline to respond

Please list your present medications and dosages: (include birth control pills/vitamins):

****

PAST HISTORY
Do you or have you ever had?

	Yes	No
High Cholesterol	❑	❑
Rheumatic fever	❑	❑
High or low thyroid	❑	❑
High blood pressure	❑	❑
Heart trouble	❑	❑
Disease of arteries	❑	❑
Musculoskeletal injury	❑	❑
Lung disease	❑	❑
Operations	❑	❑
Back injury	❑	❑
Epilepsy	❑	❑
Diabetes	❑	❑
Other		

PRESENT HISTORY
Have you recently had?

	Yes	No
Chest pain	❑	❑
Shortness of breath	❑	❑
Heart palpitations	❑	❑
Cough on exertion	❑	❑
Coughing blood	❑	❑
Back pain	❑	❑
Painful, stiff or swollen joints	❑	❑

If yes to any of the above, please explain:______________________________

____

Date of last physical? Physician

Health Habits:

Do you smoke? ☐ Yes ☐ No
If yes, how many cigarettes per day?______

Do you drink alcohol? ☐ Yes ☐ No
If yes, how many drinks per week? ______

Women Only:

1. Age of first menstrual period?_________
2. Have your menstrual periods been regular (10-12 periods per year)?

   ☐ Yes ☐ No

   a. If no, please summarize your menstrual history:

3. Are you taking oral contraceptives? ☐ Yes ☐ No
   a. If yes, for how long?_______
4. What was the date of your last menstrual period?___________
5. Are you pregnant? ☐ Yes ☐ No
6. Have you been diagnosed with endometriosis? ☐ Yes ☐ No
   a. If yes, are you taking medications? ☐ Yes ☐ No
   b. If yes, what medications?__________________________

APPENDIX E: Physical Activity Questionnaire

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
PHYSICAL ACTIVITY QUESTIONNAIRE

Name:______________________________ **Date**:____________

1. Do you walk to school (yes / no)? If so how long does it take (minutes)?

2. What do you normally do during a break in class or lunch?

3. Frequency of physical education classes (times per week): if 0 go to question #5.

   0 1 2 3 4 5

4. Length of physical education classes (in minutes):

   0 <20 30-35 35-40 40-45 45-50 50-55 55-60 60+

5. Television watched (# hours after school/evening)?

School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+
Non School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+

6. Computer/video games played (#hours after school/evening)?

School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+
Non School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+

7. Study or do homework (#hours after school/evening)?

School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+
Non School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+

8. Sleep (hours per night)?

School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+
Non School Nights:	none	½-1	1-2	2-3	3-4	4-5	5+

OVER

9. Time spent each week doing the following activities:

	0	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11+
Cycling												
Swimming												
Running/												
Dance/Ballet												
Baseball												
Basketball												
Soccer												
Tennis												
Gymnastics												
Karate												
Football												
Hockey												
Horse Riding												

10. Participation in team sports (yes / no)?

Sport #1		***Sport #2***	
Age started:		Age started:	
# practices/week:		# practices/week:	
# weeks in season:		# weeks in season:	
# years participation:		# years participation:	

Sport #3		***Sport #4***	
Age started:		Age started:	
# practices/week:		# practices/week:	
# weeks in season:		# weeks in season:	
# years participation:		# years participation:	

Slemenda CW, Miller JZ, Hui SL, Reister TK, Johnston, Jr CC. Role of physical activity in the development of skeletal mass in children. *J Bone Miner Res.* 6:1227-1233,1991.

APPENDIX F: Block Dietary Questionnaire

KIDS' FOOD QUESTIONNAIRE

Child's name ______________________________

Today's Date ______________________________

This survey is about all the food your child eats, either at home or at school or at a friend's house. Please fill it out together.
There are no right or wrong answers. It is very important that we learn what your child actually eats, not what he or she should eat.
The survey will take about 30 minutes.

- Use ONLY a number 2 pencil, NOT a pen
- Fill in the circles completely
- Erase completely if you make changes

Correct Mark ●

Incorrect Marks

OFFICE USE ONLY

TODAY'S DATE (MO. | DAY | YR.) | AGE | WEIGHT pounds | HEIGHT ft. in.

RESPONDENT ID NUMBER

Child's Sex
○ Male ○ Female

Child's weight: ☐☐☐ Pounds

Child's Age ☐☐

Last week, was your child's diet typical of the way he or she usually eats?
○ Yes
○ No, he was sick
○ No, another reason

Child's height:
☐ Feet ☐☐ Inches

The next pages are about the foods your child eats. PLEASE READ THE DIRECTIONS on the back of the enclosed serving size pictures. Please ask your child about every food on the list.

PLEASE DO NOT WRITE IN THIS AREA

0572

Think about every time you ate anything in the past week. You can tell me you didn't eat a food at all in the past week, or that you ate it one day last week, two days last week, 3-4 days, 5-6 days, or every day.

Remember what you ate at **home**, at **school**, from **snack machines**, or from a **restaurant**.	If YES,	1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY
Either at home or at school, did you eat any **Cold cereal, like Corn Flakes, Frosted Flakes or any other kind?**	YES ○ → How many days? → NO ○	○	○	○	○	○	**See pictures.** Which bowl? ○ B ○ C ○ D
Last week, did you have **Milk on cereal?**	YES ○ → How many days? → NO ○	○	○	○	○	○	
Did you eat any **Hot cereal, like oatmeal?**	YES ○ → How many days? → NO ○	○	○	○	○	○	**See pictures.** Which bowl? ○ B ○ C ○ D
Last week, did you eat any **Eggs, including breakfast sandwiches with eggs?**	YES ○ → How many days? → NO ○	○	○	○	○	○	How many eggs do you usually eat in 1 day? ○ Just a bite ○ 1 egg ○ 2 eggs ○ 3 eggs
Did you eat any **Bacon or sausage, including breakfast sandwiches with sausage?**	YES ○ → How many days? → NO ○	○	○	○	○	○	
Did you eat any **Pancakes, waffles or French Toast?**	YES ○ → How many days? → NO ○	○	○	○	○	○	How many? ○ ½ ○ 1 ○ 2 ○ 3
Either at home or at school, did you eat **Granola bars, breakfast bars, oatmeal raisin bars, or pop tarts?**	YES ○ → How many days? → NO ○	○	○	○	○	○	How many? ○ ½ ○ 1 ○ 2 ○ 3
Last week, did you eat any **Cinnamon buns or muffins?**	YES ○ → How many days? → NO ○	○	○	○	○	○	How many? ○ ½ ○ 1 ○ 2 ○ 3
With breakfast, did you drink any **Milk, chocolate milk or hot chocolate?** *(Don't include milk on cereal)*	YES ○ → How many days? → NO ○	○	○	○	○	○	How many glasses or cartons for breakfast? ○ ½ ○ 1 ○ 2 ○ 3
At home or at school, did you drink any **Milk with lunch?**	YES ○ → How many days? → NO ○	○	○	○	○	○	How many glasses or cartons for lunch? ○ ½ ○ 1 ○ 2 ○ 3
Last week, did you drink any **Milk with dinner or a snack?**	YES ○ → How many days? → NO ○	○	○	○	○	○	How many glasses or cartons for dinner? ○ ½ ○ 1 ○ 2 ○ 3

Now tell me about the kind of **milk** you usually drink at home. ○ Whole milk ○ Reduced-fat (2%) milk ○ Low-fat (1%) milk ○ Non-fat milk ○ Lactaid milk ○ Rice milk ○ Soy milk ○ Don't know

Remember at home, at school, from snack machines, or from a restaurant.

If YES, "How many days last week"

		1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY				
Last week, did you eat any **Bananas**?	YES ○ → How many NO ○ days? →	○	○	○	○	○	How many do you usually have in 1 day?	○ ½	○ 1	○ 2	○ 3
Last week, did you eat any **Apples or pears**?	YES ○ → How many NO ○ days? →	○	○	○	○	○	How many do you usually have in 1 day?	○ ½	○ 1	○ 2	○ 3
Did you eat any **Oranges or Tangerines**? (Don't count juices)	YES ○ → How many NO ○ days? →	○	○	○	○	○	How many, in one day?	○ ½	○ 1	○ 2	○ 3
Did you eat any **Raisins, fruit roll-ups or dried fruit?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much do you usually eat?	○ A	○ B	○ C	○ D
Did you eat any **Canned fruit like applesauce, fruit cocktail**?	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** Which bowl?		○ B	○ C	○ D
Did you eat any **Other fruit, like grapes, fresh peaches or melon**?	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much do you usually eat?	○ A	○ B	○ C	○ D

Meats. Remember at home, at school, fast foods.

If YES, "How many days last week"

		1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY				
Last week, did you eat any **Hamburgers, cheeseburgers or meat loaf**?	YES ○ → How many NO ○ days? →	○	○	○	○	○	How much?	○ ½ small burger	○ 1 small burger	○ 1 large burger	○ 2 large burgers
Did you have any **Tacos or burritos** with meat or chicken?	YES ○ → How many NO ○ days? →	○	○	○	○	○	How many?	○ ½	○ 1	○ 2	○ 3
Did you eat any **Sandwiches with beef, like Hot Pockets, or meat ball subs**?	YES ○ → How many NO ○ days? →	○	○	○	○	○					
Did you eat any **Beef steak, roast beef, or beef in frozen dinners**?	YES ○ → How many NO ○ days? →	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D

Remember at home, at school, or from a restaurant.

If YES, "How many days last week"

Question		1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY				
Last week, did you eat any **Pork chops or BBQ ribs**?	YES ○ → How many days? → / NO ○	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D
Did you eat any **Fried chicken or chicken nuggets?**	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many pieces?	○ 1	○ 2 (or 6 nuggets)	○ 3	○ 4
Did you eat **Any other kind of chicken,** like chicken and gravy, chicken salad, or in frozen dinners?	YES ○ → How many days? → / NO ○	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D
Did you eat any **Fish, like fish sandwich, fish sticks,** or any kind of fish?	YES ○ → How many days? → / NO ○	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D
Did you eat any dishes like **Beef & noodles, pot pie, Hamburger Helper, stew ...**?	YES ○ → How many days? → / NO ○	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D
Did you eat any **Spaghetti, ravioli or lasagna with tomato sauce**?	YES ○ → How many days? → / NO ○	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D
Did you eat any **Macaroni and cheese?**	YES ○ → How many days? → / NO ○	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D
Did you eat any **Pizza, or pizza pockets?**	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many slices?	○ $\frac{1}{2}$	○ 1	○ 2	○ 3
Did you eat any **Hot dogs or corn dogs**?	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many hot dogs?	○ $\frac{1}{2}$	○ 1	○ 2	○ 3
Did you eat any **Lunch meat like bologna or sliced ham,** either on sandwiches or by itself? *(Remember Lunchables)*	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many slices of lunch meat?	○ $\frac{1}{2}$	○ 1	○ 2	○ 3
Did you eat any **Refried beans or bean Burritos**?	YES ○ → How many days? → / NO ○	○	○	○	○	○	How much?	○ A	○ B	○ C	○ D
Did you eat any **Vegetable soup, vegetable beef soup, or tomato soup?**	YES ○ → How many days? → / NO ○	○	○	○	○	○	See pictures. Which bowl?		○ B	○ C	○ D
Did you eat any **Other soup like chicken noodle or cup-a-soup?**	YES ○ → How many days? → / NO ○	○	○	○	○	○	See pictures. Which bowl?		○ B	○ C	○ D

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Remember at home, at school, fast foods, snack machines.	If YES,	"How many days last week" 1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY				
Last week, did you eat any **Hamburger buns, hotdog buns, or bagels** either alone or as a sandwich?	YES ○→ How many NO ○ days?→	○	○	○	○	○	How many did you have in one day?	○ 1/2	○ 1	○ 2	○ 3
Did you have any **Bread or toast,** including sandwiches?	YES ○→ How many NO ○ days?→	○	○	○	○	○	How many slices in 1 day?	○ 1	○ 2	○ 3-4	○ 5 or more
Did you have any **Tortillas** last week?	YES ○→ How many NO ○ days?→	○	○	○	○	○	How many ?	○ 1	○ 2	○ 3-4	○ 5 or more
Did you use any **Margarine or butter,** like on bread or on pancakes or on potatoes?	YES ○→ How many NO ○ days?→	○	○	○	○	○	How many times each day ?	○ 1	○ 2	○ 3	○ 4
Did you have any **Sliced cheese, Cheese Whiz, or grilled cheese sandwiches?**	YES ○→ How many NO ○ days?→	○	○	○	○	○	How many slices of cheese?	○ 1/2	○ 1	○ 2	○ 3
Did you have a **Peanut butter sandwich?**	YES ○→ How many NO ○ days?→	○	○	○	○	○	How many on those days?	○ 1/2	○ 1	○ 2	○ 3
Did you have any **Peanuts or other nuts or seeds?**	YES ○→ How many NO ○ days?→	○	○	○	○	○	How much in one day?	○ A	○ B	○ C	○ D

Vegetables. Remember at **home, at school, restaurant, or fast foods.**	If YES,	"How many days last week" 1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY				
Last week, did you eat any **Green salad?**	YES ○→ How many NO ○ days?→	○	○	○	○	○	**See pictures.** Which bowl?		○ B	○ C	○ D
If you had salad, did you have **Salad dressing** on it?	YES ○ NO ○										
Did you have **Green beans, string beans?**	YES ○→ How many NO ○ days?→	○	○	○	○	○	**See pictures.** How much?	○ A	○ B	○ C	○ D
Did you eat any **Baked beans, chili with beans, or any kind of beans?**	YES ○→ How many NO ○ days?→	○	○	○	○	○	**See pictures.** How much?	○ A	○ B	○ C	○ D
Did you eat any **Corn or corn on the cob?**	YES ○→ How many NO ○ days?→	○	○	○	○	○	**See pictures.** How much?	○ A	○ B	○ C	○ D

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Remember at home, at school, or from a restaurant or fast food.	If YES,	"How many days last week" 1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY
Last week, did you eat any **Tomatoes?** *(Don't include tomato sauce)*	YES ○ → How many NO ○ days? →	○	○	○	○	○	How much? ○ A little ○ ½ tomato ○ 1 ○ 2
Did you eat any **Greens, including spinach, mustard greens, or collards?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you eat any **Broccoli?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you eat any **Coleslaw or cabbage?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you eat **Carrots**, either raw or cooked?	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you eat any **Sweet potatoes, or sweet potato pie?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you eat any **French fries, fried potatoes or Tater Tots?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B (McD Small) ○ C (McD Large) ○ D
Did you have **any other kind of potatoes, like baked, boiled or mashed?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you eat any **Other vegetable, like peas, squash, or peppers?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you eat any **Rice?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	**See pictures.** How much? ○ A ○ B ○ C ○ D
Did you have any **Gravy**, like on mashed potatoes or on rice?	YES ○ → How many NO ○ days? →	○	○	○	○	○	
Did you have any **Ketchup, salsa, or barbecue sauce?**	YES ○ → How many NO ○ days? →	○	○	○	○	○	

Snacks and sweets. Remember what you had at home, at school, at the movies, from snack machines.

Question		If YES, "How many days last week": 1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT EATEN IN ONE DAY				
Last week, did you have any **Potato chips, corn chips or popcorn?**	YES → How many days? → / NO						How much in the whole day?	A	B	C	D
Did you eat any **Crackers**, including snack crackers like Goldfish?	YES → How many days? → / NO						How much in the whole day?	A	B	C	D
Did you have any **Nachos with cheese?**	YES → How many days? → / NO						How much?	A	B	C	D
Did you have any **Ice cream, ice cream bars or frozen yogurt?**	YES → How many days? → / NO						See pictures. Which bowl?	[illegible]	B	C	D
Did you have any **Cookies?**	YES → How many days? → / NO						How many cookies?	1	2-3	4-5	6+
Did you have any **Doughnuts?**	YES → How many days? → / NO						How many doughnuts?	1/2	1	2	3
Did you have any **Cake, cupcakes, Tasty Cake, Ho-Ho's, Twinkies, etc.?**	YES → How many days? → / NO						How many pieces?	1/2	1	2	3
Did you have any **Pie or turnovers?**	YES → How many days? → / NO						How many pieces?	1/2	1	2	3
Did you have any **Pudding?**	YES → How many days? → / NO						How much?	A	B	C	D
Did you have any **Chocolate candy, like candy bars, Hugs, M&Ms?**	YES → How many days? → / NO						How many bars?	1 small	1 medium	1 large	2 large
Did you have any **Other candy, like Gummy bears, Starburst, Skittles?**	YES → How many days? → / NO						How many packages?	1/4	1/2	1	2

Remember at home, at school, restaurant or soda machine.

	If YES, "How many days last week"	1 DAY	2 DAYS	3-4 DAYS	5-6 DAYS	EVERY DAY	USUAL AMOUNT IN ONE DAY
Last week, did you drink any **Sodas like Coke, Sprite, etc.**? *(Don't count diet soda)*	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many bottles or cans in 1 day? ○ 1 ○ 2 ○ 3-4 ○ 5+
Did you drink any **Kool-Aid or Gatorade?**	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many glasses in 1 day? ○ 1 ○ 2 ○ 3 ○ 4
Did you drink any **Sunny Delight, Hi-C, Hawaiian Punch or Ocean Spray?**	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many glasses or juice boxes? ○ 1 ○ 2 ○ 3 ○ 4
Did you drink any **real orange juice?** *(Don't count orange sodas)*	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many glasses or juice boxes? ○ 1 ○ 2 ○ 3 ○ 4
Did you drink any **Other Real fruit juices** like apple juice or grape juice? *(Remember juice boxes)*	YES ○ → How many days? → / NO ○	○	○	○	○	○	How many? ○ 1 ○ 2 ○ 3 ○ 4

In the past week, did you (the child) take any **vitamin pills**, like One-a-Day or Flintstones? ○ No ○ Yes **If yes, how many days last week?** ○ 1-2 ○ 3-4 ○ 5-6 ○ 7

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For the Adult

Does your child participate in the School Lunch Program?

○ No ○ Yes, at full price ○ Yes, at free or reduced price

Is your child (Check all that apply)

○ African American ○ Hispanic/Latino ○ American Indian, Alaska native
○ White ○ Asian ○ Other

What language do the parents usually speak at home?

○ English ○ Spanish ○ Something else

What is the highest grade in school that any adult in the household finished?

○ 1-8 ○ 9-11 ○ 12 (High School) ○ Some College ○ College Graduate

THANK YOU VERY MUCH FOR PARTICIPATING IN THIS IMPORTANT RESEARCH!

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APPENDIX G

Unadjusted Baseline and 12 Month Bone Values for Girls in the Control, Soccer, and Swim Groups (N=41))

Bone Variables	GIRLS		
	Control (N=13)	**Soccer (N=11)**	**Swim (N=17)**
WB BMC (g)	1668.3 ± 376.3	1557.5 ± 339.7	1626.4 ± 286.4
12 Month	1920.9 ± 311.4	1792.9 ± 336.4	1770.6 ± 252.3
FN BMC (g)	3.673 ± .776	3.812 ± .767	3.498 ± .667
12 Month	4.074 ± .655	4.130 ± .703	3.717 ± .631
FN BMD (g/cm^2)	.757 ± .119	.763 ± .116	.790 ± .110
12 Month	.804 ± .121	.832 ± .117	.800 ± .123
TR BMC (g)	6.087 ± 1.748	6.121 ± 2.058	6.038 ± 1.497
12 Month	7.196 ± 2.020	7.595 ± 1.996	6.656 ± 1.316
TR BMD (g/cm^2)	.680 ± .114	.701 ± .132	.682 ± .085
12 Month	.722 ± .120	.780 ± .129	.703 ± .082
Hip BMC (g)	26.139 ± 6.204	25.295 ± 6.069	25.748 ± 5.351
12 Month	29.490 ± 5.966	28.926 ± 5.124	28.011 ± 5.519
Hip BMD (g/cm^2)	.838 ± .135	.843 ± .126	.841 ± .100
12 Month	.893 ± .137	.927 ± .130	.880 ± .095
LS BMC (g)	44.203 ± 12.519	39.878 ± 11.698	42.821 ± 9.994
12 Month	51.516 ± 11.886	49.060 ± 12.619	48.862 ± 9.243
LS BMD (g/cm^2)	.831 ± .141	.795 ± .115	.817 ± .104
12 Month	.897 ± .144	.885 ± .123	.870 ± .097
Lat-LS BMC (g)	18.916 ± 5.212	16.086 ± 4.958	17.418 ± 5.142
12 Month	23.782 ± 4.530	20.632 ± 5.263	20.748 ± 4.798
Lat-LS BMD (g/cm^2)	.719 ± .096	.681 ± .104	.702 ± .098
12 Month	.804 ± .101	.793 ± .109	.769 ± .104

All values reported as means ± SD

WB=whole body; FN=femoral neck; TR=greater trocnanter; Hip=total hip; LS=lumbar spine; Lat LS=lateral lumbar spine

APPENDIX H

Unadjusted Baseline and 12 Month Bone Variable Values for Boys in the Control, Soccer and Swim Groups (N=32)

Bone Variables	**BOYS**		
	Control (N=11)	**Soccer (N=13)**	**Swim (N=8)**
WB BMC (g)	1597.6 ± 482.8	1802.9 ± 428.3	1409.2 ± 149.1
12 Month	1938.1 ± 491.6	2081.1 ± 498.1	1592.2 ± 196.1
FN BMC (g)	3.861 ± .783	4.233 ± .870	3.410 ± .302
12 Month	4.312 ± .961	4.722 ± .983 [a]	3.599 ± .451
FN BMD (g/cm²)	.803 ± .078	.822 ± .103	.732 ± .099
12 Month	.856 ± .108	.878 ± .119	.763 ± .123
TR BMC (g)	6.839 ± 2.468	8.052 ± 3.037	5.229 ± .412
12 Month	8.352 ± 2.493	9.092 ± 3.326 [a]	6.269 ± .761
TR BMD (g/cm²)	.705 ± .097	.756 ± .151	.624 ± .051
12 Month	.762 ± .119	.788 ± .143	.671 ± .064
Hip BMC (g)	26.654 ± 8.881	32.081 ± 9.748	23.343 ± 4.134
12 Month	31.151 ± 9.732	37.875 ± 10.997	27.549 ± 5.171
Hip BMD (g/cm²)	.855 ± .111	.904 ± .138	.778 ± .092
12 Month	.921 ± .142	.967 ± .151	.823 ± .107
LS BMC (g)	35.821 ± 12.614	46.092 ± 16.106	32.885 ± 3.693
12 Month	44.252 ± 15.810	55.443 ± 18.610	37.895 ± 5.748
LS BMD (g/cm²)	.719 ± .125	.787 ± .134	.706 ± .073
12 Month	.782 ± .148	.869 ± .153	.738 ± .065
Lat-LS BMC (g)	16.694 ± 5.825	21.048 ± 10.388	12.746 ± 2.396
12 Month	20.380 ± 7.952	23.993 ± 8.742	16.384 ± 3.789
Lat-LS BMD (g/cm²)	.690 ± .085	.739 ± .178	.612 ± .070
12 Month	.771 ± .136	.792 ± .140	.696 ± .086

All values reported as means ± SD

WB=whole body; FN=femoral neck; TR=greater trochanter; Hip=total hip; LS=lumbar spine; Lat LS=lateral lumbar spine

[a] Soccer greater than swim, $p \leq 0.05$