AN ABSTRACT OF THE DISSERTATION OF

Robyn K. Fuchs for the degree of Doctor of Philosophy in Human Performance presented on April 29, 2002. Title: The Growing Skeleton: Influence of Lifestyle and the Development of Normative Data for Fan Beam DXA.

Redacted for privacy

Abstract approved_

Christine Snow

To examine the potential for exercise to build bone mass during growth, objectives of this dissertation included: 1) determine the effects of 7 months of jumping followed by 7 months of detraining on hip and spine bone mass in the prepubertal children; 2) determine variables that best predict bone mineral content (BMC;g) of the hip and spine in order to develop prediction equations for healthy, Caucasian children, specific to Hologic fan-beam DXA machines; and 3) to examine the potential synergy between calcium intake and the bone response to jump training in prepubertal children. Results/Conclusions Objective 1 (Chapters 2, 3 and 4): children who performed 300 jumps/week at a load magnitude of 8 body weights had significantly greater 7-month changes for BMC at the femoral neck and lumbar spine than controls (4.5% and 3.1%, respectively), and significantly greater 7-month changes for bone area (BA; cm^2) at the femoral neck than controls (2.9%). After 7-months of detraining (no box jumping exercises) the jumping group maintained 4% greater BMC and 4% greater BA at the femoral neck than controls. By contrast, at the spine, gains in BMC from the intervention were not retained after an equivalent period of detraining. These data indicate that high-impact jumping enhances growth at the hip. Results/Conclusions Objective 2 (Chapter 5): Age, height, and weight were entered as predictor variables in order to create regression models for healthy, young Caucasian boys and girls. Of these, height and weight independently predicted

femoral neck and total hip BMC in both boys (femoral neck: R^2= .48, total hip: R^2= .63) and girls (femoral neck: R^2=.49, total hip R^2=.65). Height best predicted spine BMC in boys (R^2= .58), but both height and weight independently predicted spine BMC in girls (R^2=.54). We report that height and weight not age, best predict bone mineral content at the hip and spine. Results/Conclusions Objective 3 (Chapter 6): Children responded similarly to the jumping program regardless of calcium intake. 73% of our population had dietary intakes of calcium that met the recommended values for their age group.

THE GROWING SKELETON: INFLUENCE OF LIFESTYLE AND THE DEVELOPMENT OF NORMATIVE DATA USING DXA

by

Robyn K. Fuchs

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Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Robyn K. Fuchs, Author

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There are so many people that have been instrumental in my academic career at Oregon State. I thank my mom, dad, and sister for their never-ending loving support. My family has been a strong source of encouragement and strength for me throughout my time here at Oregon State. My parents have always encouraged me to never give up on my dreams. I thank the wonderful members of my graduate committee, Christine Snow, Toby Hayes, Dan Williams, Connie Weaver, and Marjorie Reed. This has been a wonderful group to work with. I was fortunate to have a committee that treated me very well and allowed me to grow and feel confident in the work that I have completed. I especially want to thank my advisor Christine Snow. It is hard to believe that I have now been a part of the Bone Research Lab for over 7 years. It has been a great experience working with Christine over the years. She is a tremendous role model and friend. I look forward to continuing our working relationship and friendship. I thank my dearest bone lab friend Kerri Winters for her endless support. She has been a source of support throughout my time here at OSU and continues to be my nicest girlfriend ever. I also thank my other bone lab friends Kara Witzke and Janet Shaw for helping me along the way. You are all amazing women who inspire me. I thank my multi-talented friend Jeremy Bauer for his support along the way. He always made time to help me when I had a questions, made outstanding graphics of my publications, and was fun to ride bikes with. I thank Kathy Gunter for her support along the way with both school and biking. I thank Carrie Gramer for her fun cards, generosity, and thoughtfulness. I thank Arwen, Todd, and Shantel for their help with the Kids study. I want to thank all of my wonderful practicum students who have helped me teach elementary school children the joy of box jumping. I thank all of the parents and children who volunteered to participate in my study. Without your participating and loyalty to coming in for testing measurements we would not have been able to complete this study. I also appreciate all of the help that each classroom teacher gave me and for allowing us to use your classroom time to conduct our study. Lastly, I thank my wonderful friend Darren who helps keeps me laughing.

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DEDICATION

Dedicated to my family and friends who have so graciously guided me along my educational journey.

I believe in mystery and miracles and the magic of a new day.
I believe in angels and natural wonders and the beauty inside people.
I believe in rainbows and happy endings and dreams-come-true.
I believe in a bright-and-shining tomorrow.
-Anonymous

THE GROWING SKELETON: INFLUENCE OF LIFESTYLE AND THE DEVELOPMENT OF NORMATIVE DATA USING DXA

CHAPTER 1

INTRODUCTION

Osteoporosis is defined as a disease characterized by low bone mass and microarchitectural deterioration, with a subsequent increase in bone fragility and susceptibility to fracture (NIH Consensus Report, 2002; Anonymous, Consensus Development Statement). This definition has been operationally defined by the World Health Organization as a bone mineral density t-score that is less than 2.5 standard deviations below the mean peak value of young adult women (Kanis, Melton, Christiansen, Johnston and Khaltaev, 1994). Criteria for diagnosing osteoporosis for men and children, and different ethnic backgrounds have not been established (NIH Consensus statement, 2001). Recent prevalence estimates from the National Osteoporosis Foundation report that nearly 44 million US men and women over the age of 50 have either low bone mass (osteopenia) or osteoporosis. As life expectancy continues to increase, this estimate is expected to grow to more than 52 million men and women by the year 2010 (National Osteoporosis Foundation, 2002).

Osteoporosis-related fractures are a major public health problem with both economic and personal consequences. Currently there are over 500,000 hip fractures in the US alone, and over 1.7 million hip fractures worldwide (Melton, 1993). On a financial level, health care expenditures related to fractures amount to over 10 billion dollars each year, and for a patient who sustains a hip fracture, this amounts to over $7,000 to cover short-term hospitalization costs necessary to treat the fracture (Johnell, 1997). In addition to the financial burdens, fractures create serious personal hardships such as increased mortality rates, chronic pain and disability, and a decreased quality of life (Melton, 1988; Chrischilles et al., 1991; Melton and Cooper, 2001).

Osteoporosis is most often considered a disease that develops in adulthood because of normal age-related processes, such as changes in hormonal status associated with menopause. However, osteoporosis may have pediatric origins (Saggese, Baroncelli, Bertelloni, 2001; Bachrach, 2001). Researchers suggest the amount of bone mineral acquired during childhood and adolescence accounts for approximately 60% of the risk for osteoporosis in later life (Hui et al., 1990), and the susceptibility to osteoporosis may be detectable in early childhood (Ferrari, Rizzoli, Slosman & Bonjour, 1998). Thus, the attainment of optimal peak bone mass may reduce osteoporosis-related fractures (Slemenda et al., 1994; Fassler & Bonjour, 1995). Peak bone mass is defined as the maximum amount of bone mineral content (BMC;g) acquired during normal growth, with the greatest mineral content accumulated during the 2nd decade of life (Teegarden et al., 1995). Bone mass is largely controlled by genetics (60-80%) (Seeman et al., 1989; Pocok et al., 1987); however, lifestyle factors such as adequate calcium intake, regular weight-bearing physical activity, and maintaining a healthy body weight account for the remaining variance. Since our bone mass is not completely controlled by genetics skeletal health may be improved by encouraging lifestyle habits that promote bone growth.

The promotion of lifestyle habits, such as regular participation in weight-bearing physical activities and the consumption of adequate bone building nutrients, such as calcium, are two strategies that may enhance mineral acquisition during critical growing years. These strategies are recommended by the National Institutes of Health as primary aims for increasing peak bone mass, and thus preventing osteoporosis (NIH Consensus Statement, 2000). The primary aim of this dissertation focuses on the use of exercise as a strategy to improve peak bone mass. The skeletal benefits of exercise for children were first recognized in cross-sectional and observational studies of active versus non-active children, with active children possessing higher bone mass than their non-active counterparts (Slemenda et al., 1991; Grimston et al., 1993). From these studies it was inferred that the type of activity performed was central to the desired bone response. Specifically, children participating in impact activities, such as gymnastics and soccer had a skeletal advantage over those participating in non-impact activities such as swimming (Courtiex et al., 1998; Grimston et al., 1993; Slemenda et al., 1991; Cassel et al., 1996; Dyson et al.1997). More conclusive evidence has come from exercise intervention trials (McKay et al., 2000; Heinonen et al., 2000; Morris et al., 1997; Bradney et al., 1998; Mackelvie et al., 2001; Petit et al., 2002) demonstrating improved bone mass and geometry at sites of loading in those children who engage in weight–bearing exercise. In an 8-month school based jumping program, McKay and coworkers (2000) found that children between the ages of 6 and 10 who engaged in bone loading activities 3 times per week for 10 to 30 minutes had a 1.2% greater increase in femoral trochanteric bone mineral density than controls. In that study, common games such as tag were altered to include hopping and bounding, and 10 tuck jumps were also performed at each session. In a 10-month nonrandomized trial by Morris and co-workers (1997), pre-menarcheal girls engaged in impact activities (i.e. soccer, football, skipping for 30 minutes, 3 times per week had 4.5% greater bone mineral content at the femoral neck compared to controls and 5.5% greater bone mineral content at the lumbar spine compared to controls. Recently, Mackelvie and co-workers (2001) studied the bone response of prepubertal and early pubertal girls to a jumping program (10 min, 3 days/week) that was added to school-based physical education classes. After controlling for growth, there were no difference in the skeletal response in the Tanner I girls; however, the early pubertal girls (Tanner II and III) demonstrated 1.5% to 3.1% more bone at the femoral neck and lumbar spine, respectively, than controls. The aforementioned studies provide evidence that various types of impact activities may effectively stimulate mineral accrual in the pediatric skeleton. In addition, data from these studies has allowed researchers to work towards defining exercise prescriptions for children that target improving bone mass. A primary goal of this dissertation was to conduct an intervention at a local elementary school that targets one specific mode of exercise as a means to increase bone mass in young children. In chapter 2 data are presented from a longitudinal exercise intervention trial that uses box jumping as a means to increase bone mass in young children.

If exercise is to be used as a strategy to improve peak bone mass an important question to address is the long-term skeletal benefits of exercise. Specifically, will bone gained from exercise training be maintained if a child stops exercising, or reduces their activity levels? Bone that is not subjected to a significant amount of loading, either from prolonged bed rest, immobilization, or activities non-conducive in promoting bone mineralization result in bone loss (Donaldson et al., 1970; Uhthoff & Jaworski, 1978; Turner & Bell, 1986). In the mature skeleton of both humans and animals, bone gained from exercise training is lost when activity is withdrawn (Winters & Snow, 2000; Dalsky et al., 1988; Snow et al., 2001; Yeh & Aloia, 1990). However, in the growing skeleton of animals, limited evidence suggest that bone gained from exercise training is retained after a period of exercise withdrawal (Kiuchi, Arai, & Katsuta, 1998; Singh et al., 2002). Results form these studies provide encouraging evidence that the growing human skeleton may also retain bone gained from added mechanical loading. To date, there are no reported intervention trials in the growing skeleton that have examined how growing bone would respond when exercise training is either reduced or discontinued. In Chapter 4 data are presented for a group of children who had participated in a 7-month randomized controlled intervention trial that included a 7-month detraining period. The aim of this intervention trial was to examine the effects of detraining on hip and spine bone mineral content and bone area in a group of children who had completed a 7-month jump training intervention.

The ability for researchers to evaluate the effectiveness of an intervention trial, or the skeletal health of a child requires normative data on healthy children that are age, gender, and race specific. Over the last three decades several safe, noninvasive measurement tools have been developed to assess bone mass [(single photon absorptiometry (SPA), dual photon absorptiometry (DPA), quantitative computed tomography (QCT), and dual energy x-ray absorptiometry (DXA)]. Of these, DXA has become the gold standard for measuring bone mass due to the machines high precision, short scan time, and minimal radiation exposure. Since the conception of DXA, only a few studies have reported norms specific to this technique for children. (Kroger et al., 1993; Warner et al., 1998; Salle et al., 1992), with a majority of the data being reported for SPA and DPA machines (DeSchepper et al., 1991; Proesmans et al., 1994; Ponder et al., 1990; DeSchepper et al., 1995). In addition, DXA technology has made new technology advances, with pencil-beam DXA being replaced with DXA instruments that use fan-beam technology. Due to reported differences between machine types (Ellis & Shypailo, 1998; Barthe et al., 1997), it is necessary to develop normative data that are machine and software specific. To our knowledge, there are no published reports of hip or spine normative data for Caucasian pre-pubescent boys and girls using the Hologic, 4500A, fan-beam densitometer. In Chapter 3 normative data are presented that are age, gender, and race specific for healthy children between the ages of six and 10 years. Our aim was to determine the variables that best predict bone mineral content of the hip and spine and develop regression equations for healthy, Caucasian children specific for fan beam densitometers.

In addition to exercise, dietary calcium intake is another lifestyle factor associated with peak bone mass attainment (Slemenda et al., 1991; Johnston et al., 1992; Matkovic et al., 1990). Calcium is the primary nutrient stored within our skeleton, and is a powerful nutrient required for the growth, development, and maintenance of both the immature and mature skeleton. Calcium supplementation trials provide evidence that calcium intake through either calcium supplementation or calcium enriched-foods improves skeletal health across all stages of development (Johnston et al., 1992; Lee et al., 1997; Dibba et al., 2000; Lloyd et al., 1993). However, data examining the interactions between calcium intake, exercise, and bone in the growing skeleton are limited (Ruiz et al., 1995; Vandenbergh et al., 1995; Welten et al., 1994; Valimaki et al., 1994), and have not been evaluated in randomized, controlled trials. Thus, the interaction between how exercise and calcium interact is poorly understood. Of the cross-sectional investigations that have evaluated the relationship between dietary calcium and exercise in the growing skeleton, physical activity appears to be a stronger predictor of bone mass than calcium, and some researchers have reported a significant influence of physical activity on bone mass of the hip, spine, and radius despite calcium intake levels that are below the recommended levels (Ruiz et al., 1995; VandenBergh et al., 1995). However, the cross-sectional nature of these investigations limits their interpretation. In chapter 6 preliminary data are presented for an ancillary study examining the bone response to exercise training in children with varying levels of calcium intake. Our aim was to examine the permissive role of calcium on the bone response to mechanical loading in pre-pubertal children.

CHAPTER 2

JUMPING IMPROVES HIP AND LUMBAR SPINE BONE MASS IN PREPUBESCENT CHILDREN: A RANDOMIZED CONTROLLED TRIAL

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ABSTRACT

Physical activity during childhood is advocated as one strategy for enhancing peak bone mass (bone mineral content, BMC) as a means to reduce osteoporosis-related fractures. Thus, we investigated the effects of high-intensity jumping on hip and lumbar spine bone mass in children. Eighty-nine pre-pubescent children between the ages 5.9 and 9.8 years were randomized into a jumping (n=25 boys, n=20 girls) or control group (n=26 boys, n=18 girls). Both groups participated in the 7-month exercise intervention during the school day, three times per week. The jumping group performed 100, two footed jumps off 61 cm boxes each session, while the control group performed non-impact stretching exercises. BMC (g), bone area (BA; cm^2), and bone mineral density (BMD; g/cm^2) of the left proximal femoral neck and lumbar spine ($L_{1\text{-}4}$) were assessed by dual-energy X-ray absorptiometry (Hologic QDR/4500-A). Peak ground reaction forces were calculated across 100, two-footed jumps from a 61-cm box. In addition, anthropometric characteristics (height, weight, and body fat), physical activity and dietary calcium intake were assessed. At baseline there were no differences between groups for anthropometric characteristics, dietary calcium intake, or bone variables. After 7-months, jumpers and controls had similar increases in height, weight, and body fat. Using repeated measures analysis of covariance (ANCOVA; covariates: initial age and bone values, and changes in height and weight) for BMC, the primary outcome variable, jumpers had significantly greater 7-month changes at the femoral neck and lumbar spine than controls (4.5% and 3.1%, respectively). In repeated measures ANCOVA of secondary outcomes (BMD and BA), BMD at the lumbar spine was significantly greater in jumpers than controls (2.0 %), and approached statistical significance at the femoral neck (1.4%, p=.085). For BA, jumpers had significantly greater increases at the femoral neck than controls (2.9%), but were not different at the spine. Our data indicate that jumping at ground reaction forces of eight times body weight is a safe, effective, and simple method of improving bone mass at the hip and spine in children. This program could be easily incorporated into physical education classes. (J Bone Miner Res 2001;16:148-156).

Key Words: pre-pubescent children, exercise intervention, bone mineral content, bone area, bone mineral density,.

INTRODUCTION

Osteoporosis is a disease of crisis proportions. Low bone mass is a major contributing factor associated with osteoporosis-related fractures.[1-3] The most effective way to prevent osteoporosis may be to increase bone mineral content (BMC) during childhood, thereby developing a stronger skeletal foundation to offset age related bone loss. [4-5]

Physical activity is advocated as one strategy for enhancing peak bone mass during childhood as a means to reduce osteoporosis-related fractures.[4-5] Both cross-sectional and longitudinal investigations have documented the positive effect of physical activity on growing bone, reporting higher bone mass in active children compared to non-active children.[6] More specifically, children engaged in high intensity weight bearing activities such as gymnastics and ballet [7-11] have higher bone mass when compared to children involved in low intensity weight-bearing activities such as walking and swimming.[8,10-11] Evidence that physical activity may be an effective strategy for the prevention of osteoporosis may also be inferred from cross-sectional investigations of retired athletes, demonstrating higher bone mass with a history of childhood weight bearing physical activity.[9, 12-15] Therefore, the development of "bone loading" exercise programs targeted at increasing bone mass during childhood have important implications as prevention strategies for osteoporosis. The ideal program is one that could easily and safely be incorporated into a physical education curriculum.

Based on the theory that high intensity forces elicit greater changes in bone mass than low to moderate intensity forces, [16-17] we used gymnastics as a model to develop a highly specific jumping program and tested its efficacy in pre-pubescent children. The program was designed to produce ground reaction forces of eight times body weight when jumping from a 61-cm high box, less than gymnastics (10-15 times body weight), but higher than those reported from running (2-3 times body weight).[18] We define high intensity as forces greater than four times body weight, moderate intensity as two to four times body weight and low intensity as less than two times body weight.[19] Thus, the aim of this investigation was to examine the effects of a high intensity jumping program on hip and lumbar spine BMC in prepubescent children.

MATERIALS AND METHODS

Design and participants

The exercise program was incorporated into the curriculum of an elementary school in Corvallis, OR. This school was selected based on the large number of children enrolled in the primary classrooms (kindergarten through third grades). Those children given parental permission to participate (testing measurement and exercise intervention) were randomly assigned by gender to either a jumping or control group, on their first visit to the laboratory.

One hundred and twenty children were enrolled in five primary classrooms (approximately 25 children per classroom; Fig. 1). One hundred of these children (51 boys and 49 girls) were given parental permission to participate. The parent of each child completed a standard health and physical activity questionnaire prior to participation to identify inclusion into the study. Exclusion factors included disorders or medications known to affect bone metabolism, thyroid disease, diabetes, chronic diseases or orthopedic problems that may limit training and testing, body weight that exceeds 20% of the recommended weight for height and age, and a change in Tanner stage from baseline. One boy exceeded 20% of the recommended weight for height and age and was excluded. Seven children did not return for post-testing, including 3 jumpers (1 boy, 2 girls) and 4 controls (2 boys, 2 girls). Of these children, 4 moved, 2 parents became concerned with x-ray exposure and 1 parent did not have time for testing.

Eighty-nine children (45 jumpers and 44 controls) completed the intervention and had ethnic backgrounds as follows: 87 Caucasian, 1 Asian girl and 1 Caucasian-Hispanic girl. This study was approved by the Oregon State University Institutional Review Board, and the Oregon Board of Radiology. Parents of all children gave written informed consent prior to participation. All testing measurements were conducted at the Bone Research Laboratory over a 2-week period at baseline and at the completion of the 7-month exercise intervention.

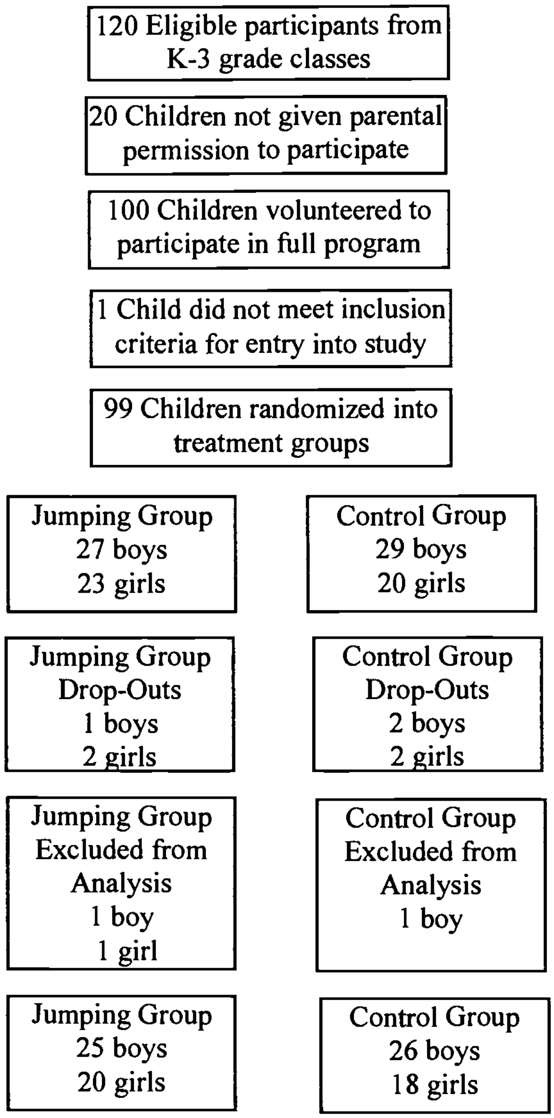

Figure 2.1 Participant profile

Anthropometric measurements and secondary sexual characteristics

Height and weight were measured in light indoor clothing without shoes. Height was recorded to the nearest 0.1 cm using a wall-mounted stadiometer (model S-220; Seca, Hanover, MD, USA) and weight was recorded to the nearest 0.1 kg using a Seca electronic weighing scale (model #770; Seca). Body fat was estimated using gender specific prediction equations formulated by Williams and co-workers.[20] Two anatomical sites (triceps and subscapular) were measured on the participants right side using Lang (Cambridge Scientific Industries, Inc., Cambridge, MD, USA) skinfold calipers (precision error = 2%, based on a subsample of 20 children randomly chosen from our population). The same technician performed all anthropometric measurements.

Tanner stages were used to assess sexual maturation.[21] Parents were given line drawings and written explanations of each developmental stage, using pubic hair in boys, and both pubic hair and breast development in girls. A researcher knowledgeable with the Tanner stage criteria was available to answer questions.

Bone measurements

BMC (g), bone area (BA: cm^2), and bone mineral density (BMD:g/cm^2) of the left proximal femoral neck and lumbar spine (L_{1-4}) were evaluated by dual energy X-ray absorptimetry (Hologic QDR/4500-A; Waltham, MA). Bone measurements of the hip and lumbar spine have an in-house precision error of 1-1.5% based on adult scans. It was not possible to develop precision error for children in our laboratory due to increased X-ray exposure. Hip scans were performed using a positioning apparatus that held the left leg in an internally rotated position of 30°. Because of the small femoral neck size of the children in our study, the default femoral neck box of 14 pixels was reduced to ensure that the head of the femur was not included in the analysis. The femoral neck region of interest established for each child remained constant for pre and postanalyses.[22] Lumbar spine scans were performed with the child positioned in a supine position with the knees at 90°of flexion, elevated on a semi-soft box provided by Hologic, Inc. Low-density threshold spine software was used to analyze all lumbar spine scans.[23]

Ground reaction forces

Peak ground reaction forces were calculated in a subsample of volunteers (n=16 jumpers, n=8 stretchers) at post-testing. Children from both groups were measured to obtain data on children with and without jumping experience. Children were asked to perform 100 two-footed jumps onto a 40 cm X 60 cm force plate (model 9281B; Kistler Instrument Corp., Amherst, NY, USA) from a height of 61 cm over a period of approximately 15 minutes. Verbal and visual instructions for how to perform the jumping exercises were given to each child. After each jump trial was completed, participants returned to the 61 cm box by first stepping onto a 20 cm box, then to the 61 cm box. Each subject was allowed to proceed through the 100 trials at his/her own pace. A trial was considered acceptable when both feet made complete contact with the force plate. An ideal assessment of the kinetics of each leg on landing would require two force plates or landing on the force plate with one leg on the force plate and one leg off. However, for the purpose of this study it was assumed that each leg was subjected to exactly half of the total measured ground reaction force. It was thought that the children would not perform the jumps naturally if they were required to target half of the force plate. An average value for the peak ground reaction force was calculated across 100 trials.

Physical activity and calcium intake

Physical activity was assessed by parent and child using a self-report physical activity questionnaire developed for older children and adolescents.[6] Baseline physical activity data pertains to activities a child engaged in during the previous school year, and post testing physical activity data pertains to activities a child engaged in during the intervention school year. Because of difficulties in obtaining accurate information on the amount of time spent participating in various non-organized physical activities, we report data on the mode, frequency and duration of organized physical activities (i.e team sports and lessons) and the number of children who reported engaging in various non-organized activities. The same researcher at baseline and post intervention verified information obtained from this questionnaire.

Dietary calcium intake was obtained using the Harvard Medical School Youth Diet Survey developed for older children and adolescents between the ages of 9 and 18.[24] This questionnaire was designed to be self-administered; however, due to the age of the children in our study, a parent of each child was responsible for completing this questionnaire with his/her child.[25] A researcher knowledgeable with the food survey was available to answer questions regarding the classification of foods and food serving sizes. Food models were provided to aid in estimating serving sizes. Completed food surveys were sent to Harvard Medical School for analysis.

Exercise intervention

The exercise intervention was conducted from October (1998) to May (1999), during which time 3 weeks were taken off for winter break, and 1 week was taken off for spring break. All children were involved in regularly scheduled physical education classes once a week for 30 minutes, taught by a physical education teacher at the elementary school. Our exercise program was incorporated into the regular school schedule, 3 times per week for 20 minutes, and took place on separate days from the regularly scheduled physical education classes. Since the exercise program was included as a regular classroom activity, all 120 children enrolled in the primary classrooms were required to participate in the exercise program. A teacher from each primary classroom attended the exercise classes to monitor behavior and participation.

A total of 73 exercise sessions took place during the 7-month exercise intervention. A researcher from our lab led the jumping and stretching classes, in addition to four instructors trained in teaching elementary school-aged children. The children were exposed to the same exercise instructors for the entire duration of the exercise program. The general format for each exercise class included a 5-minute warm up, 10 minutes of either jumping or stretching and a 5-minute cool down. Compliance was maintained by providing the children with game days once a month, intrinsic and extrinsic motivation, and classroom awards. Children in both groups were asked not to perform the jumping exercises outside of the regularly scheduled intervention classes. A researcher from both exercise groups maintained a record of attendance, lesson plans, injuries, illnesses, and the number of jumps and/or stretches completed each session. Attendance was calculated based on the total number of classes completed by each participant, divided by the total number of exercise classes.

Jumping group program: Jumps were performed in a unilateral direction off of 61 cm boxes (Figure. 2.2). A 20 cm box was placed in front of the 61 cm box as a step onto the higher box. Children were taught to jump off of the box with straight posture and land flat footed with the knees slightly bent. Jumping classes took place in the school gymnasium on a wooden floor and all children were required to wear shoes when jumping. The first week (3 sessions) was spent learning correct, safe jumping techniques without using the boxes. By the second week the children progressed to the 61 cm boxes, using the 20 cm boxes as a step. Children progressed from 50-80 jumps per day over the next 12 sessions, increasing 10 jumps per week. At the start of the fifth week, 100 jumps per day were performed for the remaining 58 sessions. To provide variety, boxes were arranged in rows, circles, and other patterns using between 10 to 20 boxes. For example, 20 boxes would be arranged in the shape of a triangle and the children would perform five laps around the triangle, totaling 100 jumps. After the completion of each jump, children would walk/skip/run to the next box and then step up onto the next box prior to jumping. Children did not jump up onto the boxes. To ensure that an accurate number of jumps were completed, the children placed straws, beanbags, and other objects into large baskets after completing each jump.

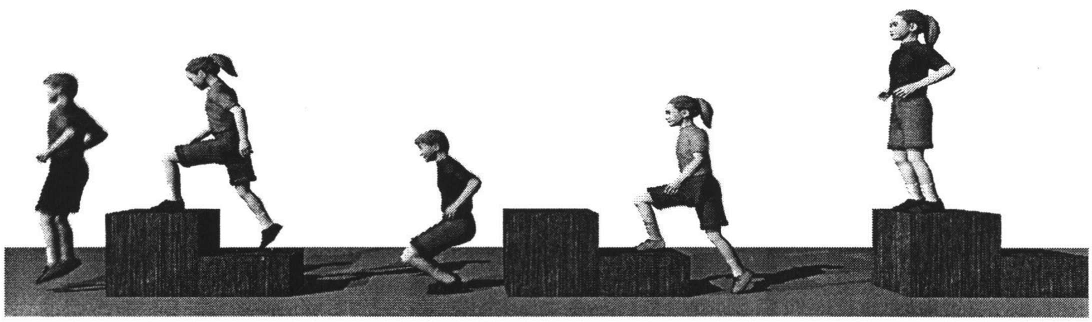

Figure 2.2. Pictorial representation of the jumping exercises. Children performed 100 two-footed drop landings off of a 61 cm high box onto a wooden floor three times per week (Image by Jeremy Bauer).

Control group program: The control group had equivalent contact time with their instructors and performed non-impact stretching exercises while their classmates were jumping. Six to eight upper and lower body exercises were completed each session. Stretches were held for 15 to 60 seconds, and children performed one to two repetitions of each exercise.

Statistical analyses

All data were analyzed using SPSS version 9.0 (SPSS, Chicago, IL, USA). Univariate analysis of variance (ANOVA) was used to examine baseline differences between the jumping and control group for all anthropometric characteristics, dietary calcium intake and bone variables (bone mineral content, bone area and bone mineral density of the femoral neck and lumbar spine). Analysis of covariance (ANCOVA) analyses were performed to evaluate the effects of the intervention for each bone variable. Absolute difference scores (post intervention value - baseline value) were entered as the dependent measure, group was entered as the fixed variable and initial age and bone values, and height and weight change values were entered as covariates. Rationale for using covariates is based on literature identifying age, height and weight as influential factors on the growing skeleton. [6, 26-30] Because BMD does not accurately correct for changing bone geometry in the growing skeleton, BMC was the primary outcome variable as it reflects both the material and geometric properties. [31] Significance level is reported as an alpha level at or below 0.05 and all data and graphs are presented as means ± SEM.

RESULTS

Subject characteristics

Jumpers and controls were similar at baseline and the completion of the intervention for all anthropometric characteristics (Table 2.1). All children were classified as Tanner stage I at baseline and post-testing. Tanner stage I is noted as pre-pubertal, with no signs of secondary sexual characteristics. One girl was excluded from the final analyses due to a change in Tanner stage at baseline (stage I) to post-intervention (stage III). Inclusion of her values did not influence the overall effects of the intervention.

Table 2.1 Baseline and post intervention anthropometric characteristics by group.

	Jumpers n=45	**Controls** n=44
Age (years)		
Baseline	7.5 ± 0.16	7.6 ± 0.17
Post	8.1 ± 0.16	8.2 ± 0.17
Height (cm)		
Baseline	125.1 ± 1.3	126.8 ± 1.2
Post	128.7 ± 1.3	129.9 ± 1.2
Weight (kg)		
Baseline	27.1 ± 0.8	28.0 ± 1.0
Post	28.8 ± 0.8	29.7 ± 1.1
Body Fat (%)		
Baseline	19.5 ± 0.9	20.7 ± 0.9
Post	20.1 ± 0.9	20.5 ± 1.1

Values reported as mean ± SEM. ANOVA: $p > .05$

Bone measurements

At baseline, jumpers and controls had similar values for BMC, BA, and BMD at the femoral neck and lumbar spine (Table 2.2). After 7-months of exercise, in repeated measures ANCOVA (covariates: initial age and bone values and height and weight change values) jumpers had significantly greater changes in femoral neck bone mineral content (0.150 ± 0.016 vs. 0.066 ± 0.016, for jumpers and controls, respectively, $p< .001$) and femoral neck bone area (0.161 ± 0.014 vs. 0.083 ± 0.014, for jumpers and controls, respectively, $p<0.001$). Both jumpers and controls had similar changes in femoral neck bone mineral density (0.022 ± 0.003 vs. 0.014 ± 0.003, respectively, $p >.05$) (Table 2.2, Figure 2.3). Jumpers had significantly greater changes in lumbar spine bone mineral content (1.956 ± 0.184 vs. 1.26 ± 0.19, respectively, $p<.05$) and lumbar spine bone mineral density (0.021 ± 0.003 vs. 0.010 ± 0.003, respectively, $p<.01$) than controls. There were no significant changes between groups in lumbar spine bone area (jumpers 2.01 ± 0.240 vs controls 1.57 ± 0.243, $p >.05$) (Table 2.2, Figure 2.3).

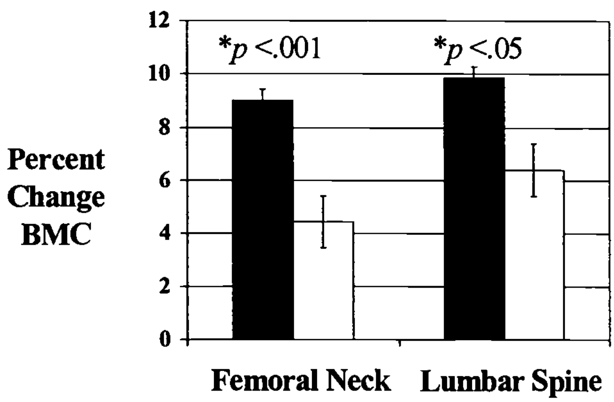

Figure 2.3 Seven month changes in femoral neck and lumbar spine bone mineral content were significantly greater in jumpers (n= 45, black bar) than controls (n=44, white bar). Values reported as percent change (%), mean ± SEM.

Table 2.2 Baseline and post intervention values by group for femoral neck and lumbar spine bone mineral content (BMC), bone area (BA), and bone mineral density (BMD).

	Jumpers (n=45)		**Controls (n=44)**	
	Baseline	Post intervention	Baseline	Post intervention
Femoral Neck				
BMC	1.84 ± 0.07	2.00 ± 0.07 [c]	1.82 ± 0.06	1.89 ± 0.06
BA	2.99 ± 0.08	3.13 ± 0.08 [c]	2.89 ± 0.06	2.96 ± 0.07
BMD	0.613 ± 0.010	0.635 ± 0.009	0.623 ± 0.010	0.638 ± 0.010
Lumbar Spine				
BMC	20.10 ± 0.51	22.06 ± 0.57 [a]	20.39 ± 0.55	21.64 ± 0.58
BA	36.43 ± 0.67	38.44 ± 0.68	37.35 ± 0.68	38.91 ± 0.66
BMD	0.550 ± 0.008	0.571 ± 0.008 [b]	0.543 ± 0.008	0.553 ± 0.008

Values reported as mean ± SEM.
ANCOVA, between groups: controlling for age, baseline bone values and height and weight change scores: p<.05[a], p<.01[b], p<.001[c]

Exercise intervention compliance and injury

There was an overall attendance (compliance) of 96% (range of 86-100%). Class absences were due to illness, injuries (not associated with the exercise intervention), vacation and school related activities. There was no correlation between the number of classes attended and the bone response to the exercise intervention.

No major injuries occurred during the exercise intervention in either the jumping or control group; however, there were occasional minor abrasions on the hands and shins in the jumping group due to bumping into the sides of the wooden boxes. No participants discontinued the exercise program due to pain or injury from the jumping or stretching exercises. At the start of the intervention some of children told the primary instructor that the jumping exercises made their feet /knees sore;

however, as the children adapted to performing the jumping exercises the number of complaints associated with foot and knee pain were reduced. There were no reports of pain or discomfort in the lower back region, hips and shins. At the completion of the intervention children in the jumping group indicated that their legs felt stronger and the exercises had become easier to perform.

Ground reaction forces

Average ground reaction forces for 100 trials were 8.8 ± 0.9 times body weight for jumpers and 8.6 ± 1.05 times body weight for controls.

Physical activity and calcium intake

Both groups reported participating in similar amounts and types of activities during the exercise intervention. Forty-nine children reportedly engaged in the following organized team sports: soccer (15 jumpers, 17 controls), baseball (7 jumpers, seven controls), gymnastics (1 jumper, 4 controls), basketball (4 jumpers, 3 controls), football (1 jumper, 1 control), swimming (1 jumper, 1 control) and roller-hockey (1 control). Organized team sport seasons were eight to ten weeks in duration, with one to three practices/games per week. During the seven month intervention 30 children (16 jumpers, 14 controls) participated in one team sport, 16 children (7 jumpers, 9 controls) participated in two team sports and three children (1 jumper, 2 controls) participated in three team sports. Six children (4 jumpers, 2 controls) started a new team sport during the study that they had not engaged in the previous school year. Of these children, two jumpers had not participated in any organized sports the previous school year. In addition to organized team sports, 70 children (31 jumpers, 39 controls) reported engaging in running activities/games after school and at recess, 54 children (29 jumpers, 25 controls) reported engaging in cycling and 26 children (15 jumpers, 11 controls) reported engaging in swimming during the seven month intervention. Only one child (jumper) reported no participation in physical activities.

Calcium intake was not significantly different between groups based on dietary information derived from the Harvard Youth Food Frequency Questionnaire. Dietary calcium intake for jumpers was 1286.9 ± 65.9 mg at baseline and 1241.5 ± 53.3 mg at post testing. For controls, dietary calcium intake was 1232.1 ± 70.3 mg at baseline and 1242.5 ± 65.7 mg at post testing. These results are based on returned questionnaires from 74 of the 89 children. Values reported for our population are slightly higher than the national average of 1200 mg for children.[32]

DISCUSSION

Our aim was to study the effects of a high intensity jumping program on hip and lumbar spine bone mineral content in the growing skeleton. We report that 300 repetitions per week of jumping, that produced ground reaction forces of eight times body weight resulted in significant improvements in femoral neck and lumbar spine bone mineral content after 7-months.

Strengths of this study include randomization, pubertal status, use of a highly specific exercise program, and the measurement of peak ground reaction forces. First, the randomized controlled design of intact classrooms eliminated self-selection bias into the exercise group, assured equivalence between groups and aided in minimizing the potential influence of hormones. Second, all children were classified as Tanner stage I (pre-pubescent), reducing the influence of sex hormones on bone. One girl advanced to Tanner stage III at post testing and was excluded from the final analysis because the development of secondary sexual characteristics is hormonally controlled.[38] Third, this is the first exercise intervention in children to use one specific exercise to increase bone mass at two clinically relevant fracture sites, the hip and lumbar spine. Other exercise interventions in children utilize a variety of different exercises, with varying intensities and durations, making it difficult to ascertain the specific exercise responsible for stimulating skeletal mineralization. [33-35] Lastly, the calculation of peak ground reaction forces in a subsample of children from the jumping and control groups allowed us to quantify the forces associated with jumping from a 61 cm box. Since ground reaction forces were not assessed at baseline we had children from our control group perform 100 jump trials to determine peak ground reaction forces in children unfamiliar with the task of jumping. The resultant forces were similar between those children experienced with the task of jumping (jumping group) and those children with no experience with the task of jumping (control group). Since peak ground reaction forces were similar between groups (eight times body weight) the forces may have been similar across the intervention period.

An important study limitation is the inability to accurately detect changes in bone geometry due to the two dimensional nature of the DXA assessment. Both bone mineral density and bone area are imperfect variables that only capture the height and width of the bone, without assessing the depth of the bone. However, bone mineral content reflects changes in the true cross-sectional area of the skeletal region being examined.[31] This may, in part explain the lack of uniform responses in area and bone mineral density from training at the femoral neck and lumbar spine.

To date, a limited number of studies have examined the effect of exercise on growing bones, all reporting a positive bone response.[33-35] In an 8-month school-based jumping program, McKay and coworkers [33] found that children between the ages of 6.9 and 10.2 years who engaged in bone loading activities three times per week for 10 to 30 minutes had a 1.2% greater increase in femoral trochanteric bone mineral density than controls. In this study, common games such as tag were altered to include hopping and bounding, in addition to ten tuck jumps performed at each exercise session (estimated ground reaction forces between two and five times body weight). In this study a majority of the children were classified as Tanner stage I; however, some girls had advanced to stage two. Although some children changed Tanner stages, when controlling for growth factors (height and weight) significant differences remained at the trochanter. However, no group differences in bone mineral density were reported at lumbar spine or femoral neck after controlling for changes in height and weight. In a 10-month nonrandomized trial, pre-menarcheal girls (Tanner stages I-III) engaged in impact activities (i.e soccer, football, skipping) for 30 minutes, three times/week.[34] Results demonstrated that exercisers had a 4.5%, 4.1% and 11.3 % greater increase in bone mineral content, bone area and bone mineral density at the femoral neck compared to controls and a 5.5%, 2.8% and 3.6% greater increase in bone mineral content, bone area and bone mineral density at the lumbar spine compared to controls. However, after controlling for increases in height and weight, no differences were observed for femoral neck bone mineral density or lumbar spine bone mineral content. These findings suggest that growth and stage of sexual maturation may have played an influential role in the resultant bone response at both the hip and lumbar spine, reducing the influence of exercise. In an 8-month trial by Bradney and co-workers,[33] pre-pubescent boys from two schools were randomly allocated to an exercise or control group. Exercisers engaged in moderate intensity physical education classes 30 minutes, three times/week. The exercise group had significantly higher bone mineral content and bone mineral density at the femoral midshaft compared to controls, and significantly higher bone mineral density at the lumbar spine ($L_{2\text{-}4}$). However, in a separate analysis of the third lumbar vertebra there were no group differences in bone mineral content or area. Results from these longitudinal investigations suggest that a variety of exercises are capable of stimulating an osteogenic response in the growing skeleton. However, due to the varied training protocols in these reports it is difficult to ascertain which exercise, or if the combination of exercises were associated with a training response. In addition, the training protocols within each investigation produced varying skeletal responses, with some positive skeletal responses removed after controlling for changes in growth.[33,34] Data from our study demonstrate significant increases in bone mass at the femoral neck and lumbar spine from a highly specific jumping program after controlling for growth.

Reports in adult premenopausal women utilizing jumping exercises as means to stimulate osteogenesis have also yielded increases in bone mass at the hip and the spine.[36-37] Heinonen and co-workers [36] reported premenopausal women to have significant increases in femoral neck and lumbar spine bone mineral density of 1.6% and 2.1% respectively, resulting from 20 minutes of an aerobic jump/step program, three times per week, with peak ground reaction forces between 2.1 and 5.6 times body weight. These percentage increases translated to adjusted mean difference scores of .012 (95% CI: .003 to .020) at the femoral neck and .015 (95% CI: 0.005 to 0.025) at the lumbar spine. Additionally, Bassey and Ramsdale[37] found that 50 jumps per day performed on the floor increased trochanteric bone mineral density by 3.4%, but not femoral neck or lumbar spine bone mineral density. Peak ground reaction forces were reported to be approximately 2 times body weight. Based on these results, and those from our investigation in children who performed jumps at 8 times body weight, impact exercise simulates osteogenesis.

Researchers have reported higher bone mass at the femoral neck in boys compared to girls;[6,8, 26-30] however, it is unclear if this difference is attributed to genetics, hormonal differences, weight bearing physical activity, or a combination of these factors. To date no studies have examined whether this relationship may be altered by exercise. Although we observed differences at baseline between genders at the femoral neck, there was no group by gender interactions at baseline or at the completion of the intervention for all bone variables. This indicates that the bone response was attributed to the high intensity nature of the jumping exercises, and was not influenced by gender.

As expected, height, weight, and body fat increased significantly within groups over the intervention period, but were not significantly different between groups. Thus, jumping exercises stimulated an osteogenic response at the hip and lumbar spine without impeding increases in height, weight or body fat, all of which are important for growth and development.[26- 36] The children in our study were slightly above the national average for calcium intake.[32] However, we found no correlations between calcium intake and any of the bone variables. Data that examine the interactions between calcium intake, bone, and exercise are limited.[39] In an exercise intervention trial, infants between 6-18 months old were randomized into a one year activity program of bone loading exercises. Results indicated that children with low calcium intake had reduced bone mineral content after performing the bone loading exercises; however those with normal calcium intakes had had greater increases in bone mass than controls. Thus, it was postulated that children who participated in exercise during growth may lose bone if calcium is inadequate. In cross-sectional investigations, calcium intake has not been associated with physical activity. By contrast, physical activity has yielded greater gains in bone despite low calcium intake. [40-41] In the present study it is not known if the exercise intervention would have been as effective if reported dietary calcium intakes were lower. Further investigations should examine the interaction between calcium intake and exercise in the growing skeleton.

No major injuries occurred from the jumping activity. The nature of the jumping exercises may present concern for long term health implications; however, there are no sporting activities which are free of injury and injury rates in youth sports are reported to be very low.[42] It is important to note that the majority of injuries that occur from high impact loading activities occur when landings are performed incorrectly.[43] The children in our study were carefully monitored to ensure that the jumping exercises were performed safely and correctly. We believe that the intensity, frequency, and number of jumps performed in this study were safe for children of this age. There is no indication that over-training occurred, as both exercise and control groups had similar gains height, weight and body fat. This is contrary to reports in children and adolescents who engage in intense exercise regimes that can result in a reduction in height, weight and body fat.[38] Thus, we believe that the jumping exercises performed in this study will not lead to long term health problems. However, we intend to follow these children in order to substantiate this claim.

Increased bone mass at the femoral neck and lumbar spine are powerful predictors of hip and spine fractures [1-2,44-45] thus, higher peak bone mass at these sites may reduce osteoporosis-related fractures. There is evidence that gains in bone mass during childhood will offset age related bone loss. For example, in retired athletes the benefit of exercise is maintained into adulthood,[9, 12-15] with greater maintenance observed in those athletes that commenced training before puberty[12, 15]. Our study provides evidence that a simple jumping program offered in the pre-pubertal years may increase peak bone mass at two clinically relevant sites, the hip and lumbar spine. Long-term follow-up will provide evidence as to whether or not these gains are maintained over time, thus potentially reduce fracture risk in adulthood. [2]

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CHAPTER 3

BOX JUMPING: A BONE LOADING EXERCISE INTERVENTION FOR ELEMENTARY SCHOOL CHILDREN

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ABSTRACT

Engaging in weight-bearing physical activities during childhood is advocated as one strategy for increasing peak bone mass to reduce the risk of childhood fractures and osteoporosis in adulthood. Peak bone mass is defined as the maximum amount of bone mass attained in ones lifetime. We recently reported that children in K-3 grades who participated in a 7-month high-impact exercise intervention program (100 box jumps off 24 inch boxes, 3 times per week) had improved skeletal health at the hip and spine, two clinically relevant fracture sites. We had children perform one simple exercise targeted at increasing bone mass to allow for easy incorporation into physical education classes or classroom settings. In this article we provide educators with detailed information on the rationale behind using box jumping to increase bone mass in children and how to incorporate the box jumping exercises into the curriculum. Box jumping is a great way for kids to increase their bone mass, and may help reduce childhood fractures and osteoporosis in adulthood. In addition, this simple exercise may help provide support and funding for including physical activity in the curriculum.

BACKGROUND

Osteoporosis is a disease of low bone mass that afflicts over 10 million individuals in the United States alone (1). The maximum amount of bone mineral accumulated in one's lifetime-peak bone mass-is usually attained by the third decade of life and naturally declines thereafter. While osteoporosis commonly arises in men and women as a result of normal age related deterioration in bone strength and density, failure to attain maximum peak bone mass may increase the risk of developing osteoporosis sooner than normal.(1,2). Since low peak bone mass is a primary risk factor for both childhood fractures and osteoporosis, attaining a higher peak bone mass during growth may be the most effective strategy for promoting life-long skeletal health.

Even though genetic factors account for a large portion of an individuals peak bone mass potential; (4,5) environmental factors such as proper nutrition and regular participation in weight-bearing physical activities may enhance peak bone mass (6). This article focuses specifically on the use of box-jumping exercises as a strategy for increasing peak bone mass. It presents the result of two longitudinal, exercise-intervention studies that demonstrate how box-jumping exercises can improve the skeletal health of children in grades K-3 and suggests a plan for implementing such exercises in schools.

EXERCISE AND BONE MASS

A large body of evidence has documented a positive correlation between weight-bearing physical activity and increased bone mass in the growing skeleton (6-10). The most effective exercises for increasing bone mass are exercises that sufficiently load the skeletal system above the level of normal daily activities. Gymnastics, jumping, volleyball, soccer, and ballet are examples of activities that have consistently been found to stimulate increases in bone mass in children. However, non-weight bearing activities (i.e. cycling, swimming) have been found to be ineffective for stimulating increases in bone mass in children (11,12).

The ability for an exercise to stimulate a positive bone response depends on the magnitude of force applied to the skeletal system, with higher magnitudes of force (greater than 4 times body weight) eliciting a greater bone response (13). We used gymnastics as a model to develop our exercise program, based on the theory that high-impact forces elicit greater changes in bone mass (12,14,15). During each practice session, gymnasts typically perform hundreds of high-impact landings that exceed 10 times their body weight, (16) with bone mass values that are 15 to 30 percent greater than inactive controls (14). The program we designed produced ground reaction forces of eight times body weight when jumping from a 24 inch box, a stimulus great enough to increase bone mass in young children at two clinically relevant fracture sites, the hip and spine (7).

BOX-JUMPING STUDIES

The Bone Research Laboratory at Oregon State University has completed two randomized, controlled, exercise intervention studies (funded by the National Institutes of Health) that examined the effects of seven months of high-impact box jumping on bone mass in children between the ages of five and nine. Our exercise programs were incorporated into the curriculum of the primary grades (K-3) at two local elementary school in Corvallis, Oregon. In the first study, we randomly assigned 100 boys and girls to either a jumping or control group. The assignments were randomized to help reduce selection bias and to ensure equivalence between group for factors such as age, height , and weight. The jumping group completed 100 jumps off 24-inch boxes, three times per week, for a period of seven months, while controls performed non-impact flexibility exercises (7). In the second study, 100 boys and girls were also randomly assigned to either a jumping or control group. However, in this study the jumping group completed 75 jumps off 24-inch boxes, two times per week, for a period of seven months (17). In both studies all children were involved in regularly scheduled physical education classes, once a week for 30 minutes. The box jumping exercises were incorporated into the regular school schedule outside of physical education class time at both schools. The exercise program for both studies took place for 20 minutes (5 minutes warm-up, 10 minutes of jumping/stretching, and 5-minute cool down). Results from these studies showed that those children who completed seven months of box jumping, consisting of 100 jumps, three times per week, had significantly greater improvements in bone mass at the hip (5%) and spine (3%), while the controls experienced no improvements(7). However, those children who completed seven months of training consisting of only half as many repetitions (75 jumps, twice per week) had no significant improvements in bone mass at the hip or spine when compared to controls (17). We are continuing our research efforts to establish the benefits of engaging in box jumping for longer durations (greater than one school year) and the benefits of box jumping on increasing bone mass in older children and adolescents.

HOW TO IMPLEMENT A BOX-JUMPING PROGRAM

Although you may feel that you do not have enough time to add another activity to your lesson, box-jumping exercises can be easily incorporated into physical education programs or classrooms. We recommend having children perform 100 jumps, three times per week to elicit the greatest gains in bone mass. However, if it is impossible to complete this many jumps, we still encourage including high-impact jumping exercises into your lessons. Table 3.1 and figures 3.1 and 3.2 provide guidelines for how to set up, perform, and implement the box jumping exercises into the curriculum. Table 3.2 provides examples for how educators may include the box-jumping exercises into their daily routine.

Table 3.1. Guidelines for box jumping

Technique	• Maintain good posture during take-off and landing. (keep back straight, keep head up). See figure 3.1. • Take-off: Jump off the box with both feet at the same time. Have your students place their hands out to the side to help with balance. • Landing: Land on both feet at the same time, with knees slightly bent.
Landing Surface	• Wood floor or carpet. If area available is concrete, place a thin mat on the floor. Make sure mat will not slide. • Don't have children jump directly onto concrete, because this can lead to potential injuries, and it hurts the student's feet and knees.
Footwear	• Tennis shoes with rubber soles.
Equipment (Figure 3.2)	• Jumps need to be performed off 24 inch boxes. An 8 inch step can be used to help children step up onto the 24 inch box. See figure 2.
Protocol	• First two weeks: spend time learning proper jumping skills starting without using boxes • Start of third week: perform 20 jumps/day, 3 times/week. Add ten additional jumps each week, progressing to 100 jumps/day, 3 times/week. • Continue performing 100 jumps/day, 3 times/week for the duration of the school year.

Figure 3.1 Box Jumping Exercises.

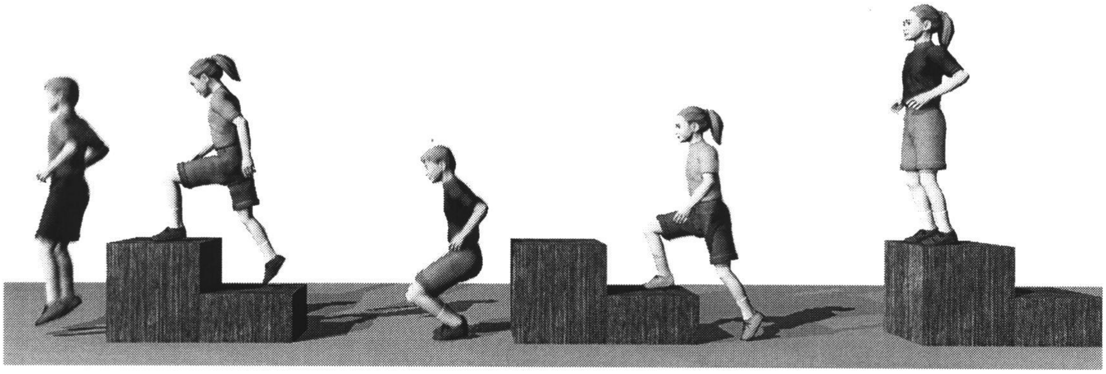


Table 3.2 Strategies for incorporating box jumping into the curriculum

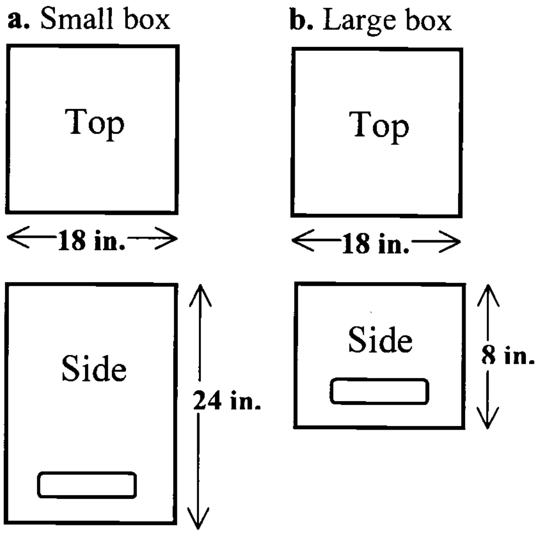
Strategy	Comment
Perform box jumps as a warm-up and then again at the end of the class.	This gives your students a break and allows for more flexibility in other lessons.
Promote the use of box jumping as a classroom activity.	Classroom teachers could have their class perform 50 jumps before they start the day and 50 jumps as a study break. This can provide teachers a fun way to keep kids alert and ready to learn during the day.
Create an "activity circuit" that positions the boxes in an organized pattern around the gym.	For example, place 20 boxes in a square around the gym/area and have your class move around the square five times to complete 100 jumps.
Provide access to boxes in hallways or playgrounds to promote use outside class.	This provides children with a reminder to include jumping at other times during the day. A parent volunteer or classroom teacher could help children monitor jumps.
Fundraising opportunity	Support a local charity or school activity by having a box-jumping-a-thon. This is a great opportunity to promote awareness for osteoporosis.
Integrate math and music with the box jumping exercises.	Use objects (bean bags/straws) to help count the number of jumps that have been completed. Alternate between box jumping and playing musical instruments. (moroccos, tambourine).
Use box jumping as the basis for Games in Physical Education.	A fun game to play is "Follow the Leader." in which the leader makes up a route through the gym that others have to follow.

SAFETY CONCERNS

No injuries occurred from the box jumping in our studies; however it is important to monitor the children carefully to ensure that they are performing the box-jumping exercises safely and correctly. Safe and correct performance of the box-jumping exercises should minimize injuries. Children in our study occasionally received minor abrasions on their hands or knees from bumping into the sides of the boxes. These minor injuries can be avoided by maintaining good class control, making sure that children do not push one another or pressure one another to perform the exercises too quickly. It is also important to required children to wear shoes while jumping, especially if the class will be jumping in an area that has a hard landing surface. The results from our study of more than 350 children indicate that correctly performed and monitored box-jumping exercises are safe and do not impede normal gains in height, weight, and body fat.

Equipment: The box jumping exercises require two box heights: 24 inches and 8 inches (figure 3.2). For our exercise program we built 20 large boxes and 20 small boxes; however, this can vary depending on the available space and funding. We built our own boxes to help reduce costs; however, boxes can be purchased. We recommend placing grip tape on the bottoms of each box to minimize sliding and to help reduce scratching of floors. In addition we recommend placing a thin piece of carpet or vinyl on the tops of the boxes. Boxes can be stacked, making it easy to store a large number of boxes in a small space. We understand that budgets are tight and funding may be limited for making boxes. The following ideas may help reduce the cost: 1) ask your local lumbar yard or community to donate material; 2) invite parents to get involved and help make the boxes; 3) have your students help by decorating the boxes or painting them colors; 4) ask your local middle school or high school shop class to make the boxes as a project.

Figure 3.2. Plans for making 8 inch and 24 inch boxes



Estimated Cost: $18-24 for two large boxes or three small boxes.
Supplies Needed: 1 sheet of 3/4 inch plywood
36 total screws (3 per edge)
Grip tape
Vinyl or carpet samples for tops of the boxes
Tacks

Directions:
Cut out four sides and one top using the dimensions provided in the illustration above. Drill three screw holes per edge and screw the sides together (screws will help make the boxes stronger than nails). After the box is assembled, sand all edges to remove rough surfaces. Place grip tape on the bottom of the box (this helps reduce boxes from sliding when they are being used). You can leave the boxes unpainted, or paint them with latex-based paint or spray paint. The handholds are an option, and they can be cut out using a saber saw. The tops of the boxes can be covered with vinyl or a carpet pad and then tacked down.
*Adapted from Pangrazi, R., 1995

CONCLUSIONS

Box jumping is a safe, easy, fun, and effective way to increase bone mass during childhood, an exercise that may be easily incorporated into physical education classes or classroom settings. Our research presents compelling evidence that performing 100 box jumps, three times per week promotes bone accumulation at the hip and spine in young children (3-5% compared to controls). Since a 5% increase in bone mass is associated with a 30% reduction in fracture risk, these dramatic results have important implications for increasing bone mass during youth and potentially reducing the progression of osteoporosis in adulthood.

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CHAPTER 4

GAINS IN HIP BONE MASS FROM HIGH-IMPACT JUMP TRAINING ARE MAINTAINED FOLLOWING DETRAINING: A RANDOMIZED CONTROLLED TRIAL IN CHILDREN

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ABSTRACT

Objectives: We have previously reported significant gains in hip and spine bone mass (bone mineral content; g) after 7-months of high-impact loading in 89 prepubertal children randomly assigned to either a jumping or control group. In that study, jumpers completed 100 jumps off 61 cm boxes 3 times/wk, while controls performed non-impact flexibility exercises. Our aim in this investigation was to evaluate the bone response to 7-months of detraining in the same cohort of children.

Study design: 74 boys and girls (n=37 jumpers, n=37 controls) from an original cohort of 89 children completed follow-up testing. Bone mineral content (BMC; g) and bone area (BA; cm^2) of the left proximal femoral neck and lumbar spine (L1-L4) were assessed by dual-energy x-ray absorptiometry. In addition, anthropometric characteristics, Tanner staging, physical activity, and average dietary calcium intake were assessed.

Results: Over 14 months, jumpers maintained 4% greater femoral neck BMC and 4% greater femoral neck BA ($p < 0.05$ and $p < 0.01$, respectively) than controls. Group differences did not persist between groups at the lumbar spine.

Conclusion: Gains in both mineral content and area at the femoral neck from high impact jumping were retained after an equivalent period of detraining. In the adult skeleton, training induced gains in bone mass diminish when mechanical loading is removed. By contrast, in the growing skeleton, our findings indicate that bone at the hip is maintained after short-term withdrawal of a carefully controlled jumping program. We conclude that this simple exercise may be useful in promoting bone growth at the hip, and thus enhance peak bone mass.

Key Words: Bone mineral content, bone area, mechanical loading, disuse, growth, exercise, osteoporosis

INTRODUCTION

Osteoporosis is a systemic bone disease that afflicts over 10 million people in the United States alone, with estimated health care expenditures that exceed $14 billion dollars each year.[1] Osteoporosis is typically thought to develop in men and women as a result of normal age-related losses in bone; however, individuals who fail to attain their maximum peak bone mass during critical growing years (childhood and adolescence) may increase their risk of developing osteoporosis.[2, 3] Therefore, it is important to implement countermeasures during childhood and adolescence that target improving peak bone mineral accrual.[1, 4]

Regular participation in weight-bearing exercise during childhood and adolescence is advocated as one strategy to enhance peak bone mass and may result in improved skeletal health in adulthood.[5, 6] Data from longitudinal exercise intervention trials in children provide evidence that simple impact activities such as jumping, that place greater than normal loads on the skeletal system, effectively increase bone mass and improve the structural properties of bone in the growing skeleton.[7-10]

Although there is growing evidence that weight-bearing exercise improves bone mass in the growing skeleton, the bone response to detraining is poorly understood in the developing skeleton. If exercise is to be used as a strategy to increase peak bone mass, it is important to understand the time course and age over which loading must be imposed. In all reports of the mature skeleton, bone gained from exercise training is lost at the hip and spine soon after a period of detraining (4 to 12 months).[11-13] By contrast, in animal models, bone mass and bone strength are maintained at loaded skeletal sites (tibia, femur) after a period of detraining. This has been documented in both young male rats who performed 10 weeks of treadmill running followed by 10weeks of detraining,[14] and in young female rats who performed 8 weeks jump training followed by 4 weeks of detraining.[15] Results form these studies provide encouraging evidence that the growing human skeleton may also retain the bone gained from added mechanical loading. In this investigation we examined the bone response to detraining in a group of young children in whom we had observed significant increases in hip and spine bone mass from a 7-month randomized controlled exercise intervention of high impact jumping.[7] Specifically, we studied the bone response at the hip and spine after jumping was discontinued for 7 months. Seven months of detraining was chosen to match the time period of the exercise intervention and to allow for one to two complete bone remodeling cycles.[16]

METHODS AND PROCEDURES

Participants and Study Design

Seventy-four children from the original cohort of 89 children returned for follow-up testing, including 37 jumpers (21 boys, 16 girls) and 37 controls (23 boys, 14 girls). Fifteen (8 jumpers and 7 controls) children from the original cohort of 89 children did not return for follow-up testing due to time constraints (n=8), parental concern for additional x-ray exposure (n=2), disinterest in testing (n=2), and moved (n=3). No children in the present study were excluded based on the exclusion criteria previously reported.[7] Ethnic backgrounds include 73 Caucasians and one Asian. All anthropometric measurements, bone measurements, Tanner staging, and questionnaires were completed at baseline, month 7 (post-intervention), and month 14 (post-detraining). All parents and their children gave written informed consent prior to participation. The Oregon State University Institutional Review Board and the Oregon Board of Radiology approved this study. All reported data are based on the 74 children whom completed follow-up testing.

Bone Measurements

Procedures. Bone mineral content (BMC; g) and bone area (BA; cm^2) of the left proximal femoral neck and anterior-posterior lumbar spine (L1-L4) were evaluated by dual-energy X-ray absorptiometry (DXA; Hologic QDR/4500-A; Hologic, Inc., Waltham, MA, USA). Bone measurements of the hip and lumbar spine have an in-house precision error of 1-1.5% based on adult scans. Precision error for pediatric DXA scans has not been developed for children in our laboratory because of excess X-ray exposure. Hip scans were performed using a positioning apparatus that held the left leg in an internally rotated position of 30 degrees. Because of the small femoral neck size of the children in our study, the default femoral neck box of 14 pixels was reduced (10-12 pixels) to ensure that the greater trochanter, ischium, and head of the femur are not included in the analysis.[17] The femoral neck region of interest established for each child remained constant for all bone scans. Lumbar spine scans were performed with the child positioned in a supine position with the knees at 90 degrees of flexion, elevated on a semi-soft box provided by Hologic, Inc. Low-density threshold spine software was used to analyze all lumbar spine scans.[18] The same technician performed all bone scans at baseline, post-testing, and detraining.

BMC vs BMD as the primary outcome variable. We use BMC rather than BMD as the primary densitometric outcome variable because BMC reflects the combined contributions of both bone density and geometry to the structural capacity in the growing child. In the adult skeleton, where changes in geometry with aging are very small, differences in BMD directly reflect differences in bone density and the use of bone area to account for within-subject changes in bone size (BMD = BMC/BA) does not confound the prediction of bone strength. However, in the growing child, where changes in both density and geometry are occurring together, the use of bone area as a normalizing variable (either as a covariate or in a ratio) to reflect changes in cross-sectional area and areal moment of inertia (which have a squared and a fourth power dependence on length, respectively) does not properly reflect the combined contributions of geometry and density to bone strength for a structure loaded in combined compression and bending. The use of BMC avoids this confounding effect. (For additional information and experimental evidence on this topic, we refer the reader to Hayes and Bouxsein[19], and Meyers and Wilson[20]).

DXA-derived area at the femoral neck as a surrogate for femoral neck cross-sectional area. In a pilot study on a cohort of 34 children, we used special software and DXA scans (Hologic 1000/W) to determine the effects of exercise on cross-sectional geometries at the mid-neck and lesser trochanter of the proximal femur. The software was developed under the direction of Dr. Hayes at the Orthopaedic Biomechanics Laboratory of the Beth Israel Deaconess Medical Center as part of a collaborative research and development agreement with Hologic, Inc. The software took advantage of direct output x-ray attenuation curves from the pencil-beam scans of the Hologic QDR-1000/W. With the upgrade in our Laboratory to the Hologic QDR-4500/A, these x-ray attenuation data were no longer available and we were unable to convince the manufacturer to undertake the considerable programming effort that would have been necessary to produce attenuation curves from the DXA scans. We thus could not acquire femoral neck cross-sectional geometry for the cohort of children reported in this paper. However, in our small cohort of children (n=34 boys and girls; n=18 jumpers; n=15 controls) who were scanned using pencil beam technology in the Hologic QDR 1000/W, we did calculate these parameters. In this group, jumping increased bone mineral content at the hip by 5.6 %. With impact loading, femoral neck cross-sectional area increased in jumpers from 1.45 ± 0.247 (SEM) cm^2 to 1.56 ± 0.277 cm^2 over the 7-month intervention. The mean increase in femoral neck cross-sectional area of 0.177 ± 0.022 (SEM) was greater in jumpers than in controls (0.086 ± 0.024 (SEM) cm^2, but this difference was not statistically significant (p=0.36) due to the lack of power (0.146). Similar results were obtained for areal moment of inertia. However, there were strong and highly significant positive correlations between femoral neck two-dimensional "area" (in the plane of the scan) and the true cross-sectional area (r^2=0.72; p<0.0001). Thus, planar area as measured in conventional DXA scans serves as a satisfactory surrogate to true cross sectional area of the femoral neck.

Anthropometric measurements and secondary sexual characteristics

Height and weight were measured in light indoor clothing without shoes. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (model S-220; Seca, Hanover, MD, USA) and weight was recorded to the nearest 0.1 kg using a Seca electronic weighing scale (model #770; Seca). Body fat was estimated using gender-specific prediction equations developed by Williams and coworkers.[21] Two anatomical sites (triceps and subscapular) were measured on the right side using Lange skinfold calipers (Cambridge Scientific Industries, Inc., Cambridge, MD, USA) (precision error = 2%, based on a subsample of 20 children randomly selected from our cohort). All anthropometric measurements were assessed using the same equipment and technician at baseline, post-testing, and detraining.

Sexual maturation was assessed using Tanner stages. Parents helped their child select the most appropriate developmental stage based on line drawings and written explanations of each Tanner stage.[22] A researcher was available to answer questions regarding the Tanner staging criteria.

Physical Activity and Calcium Intake

A self-report physical activity questionnaire developed for older children and adolescents was used to assess physical activity.[6] We report data on the mode and frequency of organized physical activities (i.e. team sports and lessons), and the number of children who reported engaging in various non-organized activities. Time spent participating in sporting activities is not reported due to difficulties obtaining accurate information on the amount of time spent participating in various non-organized physical activities. A parent helped their child complete this questionnaire, and a researcher verified the information of each questionnaire.

Average daily dietary calcium intake was obtained using the Harvard Medical School Youth Diet Survey developed for older children and adolescents between the ages of 9 and 18 years [23]. This questionnaire was designed to be self-administered; however, because of the young age of the children in our study, a parent of each child helped their child complete this questionnaire. A researcher knowledgeable with the food survey was available to answer questions regarding the classification of foods and food serving sizes, and food models were provided to aid in estimating serving sizes. Completed food surveys were analyzed by Harvard Medical School to be analyzed.

Detraining protocol

Detraining commenced immediately after the completion of the 7-month exercise intervention previously reported.[7] During the 7-month detraining period no organized jumping or stretching classes took place; however, the children were encouraged to continue all other regular physical activities. All children and their parents were asked if they had participated in the jumping activities during detraining. No children reported engaging in the box jumping exercises during the detraining period.

Statistical analyses

All data were analyzed using SPSS version 9.0 (SPSS, Chicago, IL, USA). Univariate analysis of variance (ANOVA) was used to examine baseline differences between the jumping and control groups for all anthropometric characteristics, dietary calcium intake, and bone variables (BMC and BA of the femoral neck and lumbar spine). The following analysis of covariance (ANCOVA) analyses were performed: 1) *7-month training changes:* absolute difference scores (post intervention minus baseline values) were entered as the dependent measure, group was entered as the fixed variable, and initial age, baseline bone values, and height and weight change values for the specified time period were entered as covariates; 2) *7-month detraining changes:* absolute difference scores (post detraining minus post intervention values) were entered as the dependent measure, group was entered as the fixed variable and initial age, baseline bone values, and height and weight change values for the specified time period were entered as covariates; and 3) *14-moth training plus detraining changes:* absolute difference scores (post detraining minus baseline values) were entered as the dependent measure, group was entered as the fixed variable and initial age, baseline bone values, and height and weight change values for the specified time period were entered as covariates. Rationale for using covariates is based on literature identifying age, height and weight as influential factors on the growing skeleton.[24-28] All reported data are based on the 74 children who completed follow-up testing. Significance level is reported as an alpha level at or below 0.05, and all data are presented as means ± standard error of mean (SEM).

RESULTS

Subject characteristics

Both jumpers and controls had similar gains in height, weight, and body fat over 14-months (Table 4.1). There were no significant differences between groups at baseline, month 7, and month 14 for height, weight, and body fat ($p > 0.05$). All children were Tanner stage I at the end of the 7-month exercise intervention. At the completion of detraining, 5 girls (n=2 jumpers and n=3 controls) advanced to Tanner stage II for breast development, and 3 boys (n=1 jumper and n=2 controls) advanced to Tanner stage II for pubic hair development. Those children who advanced to Tanner stage II at the completion of detraining were not excluded from analyses because removal of their values did not significantly alter results.

Table 4.1. Baseline, post intervention, and post detraining anthropometric characteristics by group.

	Jumpers n=37	**Controls** n=37
Age (years)		
Baseline	7.56 ± 0.17	7.60 ± 0.19
Post intervention	8.15 ± 0.18	8.19 ± 0.19
Post detraining	8.83 ± 0.18	8.87 ± 0.19
Height (cm)		
Baseline	125.1 ± 1.3	126.3 ± 1.3
Post intervention	128.8 ± 1.3	129.5 ± 1.3
Post detraining	132.7 ± 1.2	133.8 ± 1.3
Weight (kg)		
Baseline	26.9 ± 0.8	27.2 ± 1.2
Post intervention	28.5 ± 0.8	28.8 ± 1.2
Post detraining	30.9 ± 0.9	31.9 ± 1.4
Body Fat (%)		
Baseline	19.1 ± 0.9	20.2 ± 1.0
Post intervention	19.2 ± 0.6	20.0 ± 1.2
Post detraining	18.8 ± 0.8	19.1 ± 0.7

Values reported as mean ± SEM. ANOVA, $p > 0.05$.

Bone variables

Proximal femur: After 7 months of exercise, jumpers had significantly greater changes in femoral neck bone mineral content (post intervention minus baseline difference scores: jumpers 0.162 ± 0.015 g vs. controls 0.078 ± 0.015 g, $p < 0.001$) and femoral neck bone area (post intervention minus baseline difference scores: jumpers 0.156 ± 0.017 cm^2 vs. controls 0.071 ± 0.017 cm^2, $p < 0.001$) than controls. During the detraining period, both groups had similar gains in femoral neck bone mineral content (post detraining minus post intervention difference scores: jumpers 0.109 ± 0.015 g vs. controls 0.124 ± 0.015 g) and femoral neck bone area (post detraining-post intervention difference scores: jumpers 0.126 ± 0.017 cm^2 vs. controls 0.100 ± 0.017 cm^2). Over 14 months, jumpers maintained significantly higher femoral neck bone mineral content (post detraining minus baseline difference scores: jumpers 0.270 ± 0.019 g vs. controls 0.202 ± 0.019 g, $p < 0.05$) and bone area (post detraining minus baseline difference scores: jumpers 0.284 ± 0.020 cm^2 vs. controls 0.170 ± 0.020 cm^2, $p < 0.001$) than controls (Figure 4.1 a & b). Baseline, post intervention, and post detraining mean values for femoral neck bone mineral content and bone area are presented by group in Table 4.2.

Lumbar Spine: After 7 months of exercise, jumpers had significantly greater changes in lumbar spine bone mineral content (post intervention minus baseline difference scores: jumpers 1.866 ± 0.195 g vs. controls 1.187 ± 0.195 g, $p < 0.01$) than controls. A significant training response was not identified for lumbar spine bone area (post intervention minus baseline difference scores: jumpers 1.831 ± 0.238 cm^2 vs. controls 1.516 ± 0.238 cm^2). During the detraining period both groups had similar gains in lumbar spine bone mineral content (post detraining minus post intervention difference scores: jumpers 1.492 ± 0.216g vs. controls 1.783 ± 0.216 g) and lumbar spine bone area (post detraining-post intervention difference scores: jumpers 2.216 ± 0.252 cm^2 vs. controls 2.142 ± 0.252 cm^2). Significant between group differences did not persist after 14 months for lumbar spine bone mineral content (post detraining minus baseline difference scores: jumpers 3.371 ± 0.258 g vs. controls 2.956 ± 0.258 g). After 14 months there were no differences between groups for bone area (post detraining minus baseline difference scores: jumpers 4.076 ± 0.312 cm^2 vs. controls 3.629 ± 0.312 cm^2) (Figure 4.1 a & b). Baseline, post intervention, and post detraining mean values for lumbar spine bone mineral content and bone area are presented by group in Table 4.2

Table 4.2 Baseline, post intervention and post-detraining values by group for femoral neck and lumbar spine bone mineral content and bone area.

	Jumpers n=37	Controls n=37
Femoral Neck Bone Mineral Content		
Baseline	1.89 ± 0.07	1.79 ± 0.06
Month 7	2.06 ± 0.08[a]	1.86 ± 0.06
Month 14	2.17 ± 0.08[b]	1.98 ± 0.07
Femoral Neck Bone Area		
Baseline	3.00 ± 0.09	2.87 ± 0.07
Month 7	3.16 ± 0.09[a]	2.94 ± 0.07
Month 14	3.29 ± 0.09[b]	3.04 ± 0.08
Lumbar Spine Bone Mineral Content		
Baseline	20.62 ± 0.54	20.44 ± 0.63
Month 7	22.52 ± 0.60[c]	21.58 ± 0.64
Month 14	24.04 ± 0.67	23.34 ± 0.61
Lumbar Spine Bone Area		
Baseline	36.81 ± 0.62	37.61 ± 0.71
Month 7	38.69 ± 0.67	39.03 ± 0.71
Month 14	40.92 ± 0.77	41.15 ± 0.69

Values reported as adjusted means ± SEM.
[a]After 7 months, jumpers had significantly greater femoral neck bone mineral content and femoral neck bone area than controls based on absolute difference scores. ANCOVA, $p < 0.001$ and $p < 0.001$, respectively.
[b]After 14 months, jumpers had significantly greater femoral neck bone mineral content and femoral neck bone area than controls based on absolute difference scores. ANCOVA, $p < 0.05$ and $p < 0.001$, respectively.
[c]After 7 months, jumpers had significantly greater lumbar spine bone mineral content than controls based on absolute difference scores. ANCOVA, $p < 0.01$.

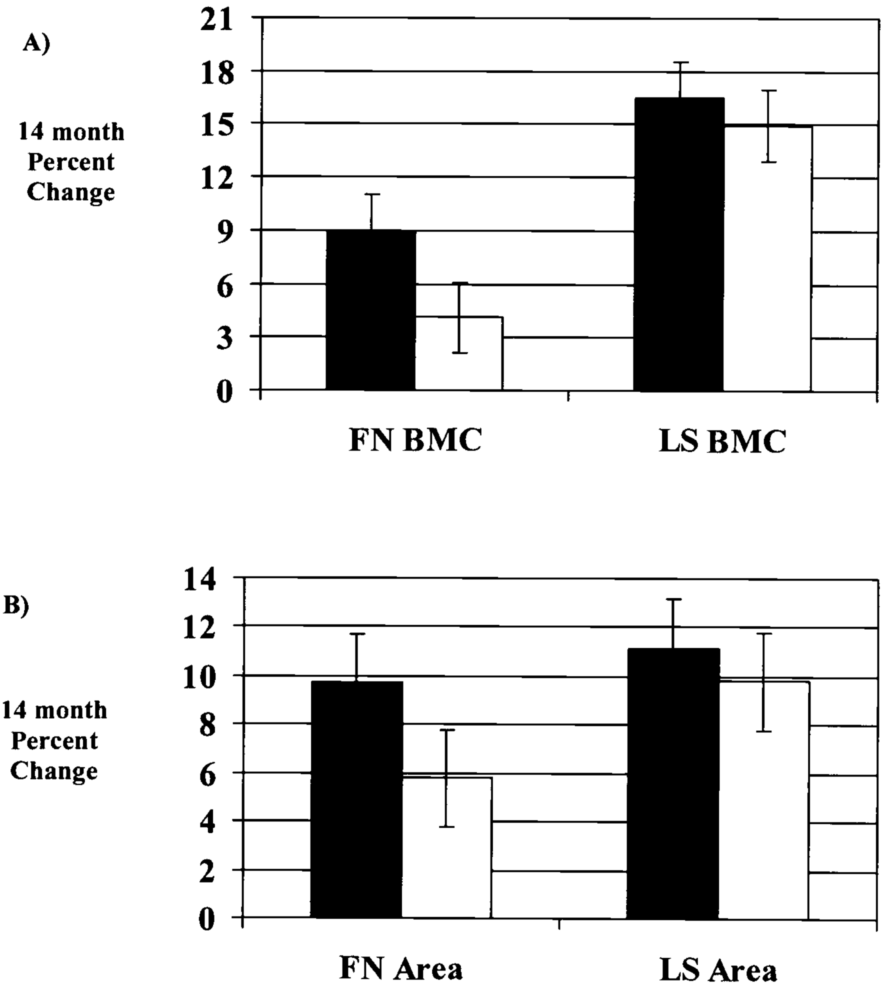

Figure 4.1 **A)** 14-month changes (exercise intervention plus detraining) in femoral neck bone mineral content were significantly greater ($p<0.05$) in jumpers (n=37, black bar) than controls (n=37, white bar). No-significant differences were observed between groups for lumbar spine bone mineral content. **B)** 14-month changes (exercise intervention plus detraining) in femoral neck bone area were significantly greater ($p<0.01$) in jumpers (n=37, black bar) than controls (n=37, white bar). No-significant differences were observed between groups for lumbar spine bone area. Values reported as percent change (%), mean ± SEM.

Physical activity and calcium intake

Both groups reported participating in similar types and amounts of activities during the detraining period. Fifty-one children reportedly engaged in the following organized team sports: soccer (n=12 jumpers, n=16 controls), baseball (n=10 jumpers, n=9 controls), gymnastics (n=2 jumpers, n=2 controls), basketball (n=8 jumpers, n=7 controls), football (n=2 controls), swimming (n=1 jumper, n=1 control) and roller-hockey (n=1 control). Organized team sport seasons were eight to 10 weeks in duration, with one to three practices/games per week. Four children (n=1 jumper, n=3 controls) started a new team sport during the detraining period. In addition to organized team sports, 68 children (n=32 jumpers, n=36 controls) participated in running activities/games after school and at recess, 59 children (n=31 jumpers, n=28 controls) engaged in cycling and 36 children (n=19 jumpers, n=17 controls) engaged in recreational swimming during the detraining period. Children from both groups participated in similar activities across all three-time points.

Average daily dietary calcium over 14 months was similar between groups (1219.4 ± 70.4 mg for exercisers and 1271.7 ± 69.3 mg for controls). These results are based on returned questionnaires from 62 of the 74 children. Mean values reported for our population are adequate based on the national recommended intake of 1200 mg/day for this age group,[29] however it is important to note that not all children in our sample met the national recommended intake.

DISCUSSION

We report that, at the hip, significant gains in both femoral neck bone mineral content and bone area from a 7-month high impact loading intervention were retained after an equivalent period of detraining. Specifically, jumpers maintained 4% greater bone mineral content and 4% greater bone area at the femoral neck than controls, 7 months after the high impact jumping exercises were withdrawn. By contrast, at the spine, the gain in bone mineral content from jump training was not retained after an equivalent period of detraining.

This study has several strengths. First, the detraining period was equivalent to the training period (7 months) and longer than most detraining periods reported in comparable studies of adults.[11-13] We designed our study to examine the bone response after an equivalent period of detraining.[11, 12] Secondly, this was a randomized, controlled exercise intervention in which only one carefully controlled and applied exercise was imposed and then withdrawn. The randomized nature of the design helped minimize selection bias, and assured equivalence between groups, thereby allowing for the determination of "dose" from exercise. Thirdly, we observed similar increases in height and weight in both groups across all time points. Thus, performing high impact jumping exercises at 8 body weights did not impede normal development (i.e. height, weight, and body fat) either during or after the intervention. Fourth, calcium intake was not a confounding variable as it was not significantly different between groups at any time point, nor did we observe a correlation between calcium intake and bone changes. However, future work is recommended to explore optimal calcium requirements for active, growing children. Fifth, our cohort of children was fairly homogenous for race/ethnicity, including 73 Caucasian and 1 Asian. Lastly, reported physical activity was similar between groups over the 14-month period.

It is important to note study limitations. First, the ability to explain changes in 3-dimensional bone geometry during growth in our population is limited by the 2-dimensional assessment of bone area using dual energy x-ray absorptiometry. Because of this limitation we used bone mineral content, not bone mineral density as our primary outcome variable since it reflects both material and geometric properties of bone (See methods section for more extensive discussion).[19] Secondly, although 66 children in this study were classified as Tanner stage I, we cannot discount the potential influence of reproductive hormones from the eight children who advanced to Tanner stage II at detraining. However, as noted previously, removing the data of these children from analysis did not change our results. A third consideration is the potential for children in both groups to continue engaging in the jumping activities. The children did not have access to the jumping boxes, and each child was asked if they continued to perform the jumping exercises on their own during the detraining period. We did not have complete control over the children during the detraining period; however, it is important to note that in other studies examining detraining in the adult skeleton, researchers also do not have complete control over their participants, and losses were still observed.[11-13]

The response of the growing skeleton to exercise withdrawal is poorly understood. Given the principle of disuse, there is an expectation that bone would respond to detraining by losing mass based on results from prospective training interventions of the mature skeleton where bone mass reverts towards baseline values soon after training is discontinued.[11, 13] Dalsky and coworkers[13] reported a 6.1% increase in lumbar spine bone mineral content in post-menopausal women engaged in 22-months of weight bearing exercise followed by a reduction of bone mass to only 1.1% above baseline levels after 13 months of reduced/discontinued activity. In this investigation not all participates completely stopped exercising during the detraining period, some participants reducing their activity level. Recently, Winters and Snow[11] reported that significant increases in bone mineral density at the greater trochanter (+2.7% exercisers, +0.8% controls) from 12 months of lower body resistance exercise plus jumping exercise in premenopausal women reverted to baseline after only 6 months of detraining. In addition, there were non-significant gains at the femoral neck (+1.2% exercisers, -0.3% controls) that significantly declined (-2.0% exercisers, -0.1% controls) after 6-months of detraining. In a prospective examination of collegiate female gymnasts nearing the age of peak bone mass attainment, gains of 1.9% to 3.7% at the hip and spine observed over 2, 8-month training seasons were followed by significant decreases of 1.2%-1.9% at the hip and spine over 2, 4-month off seasons.[12] In these athletes, although bone mineral density declined during the off-season, over 24 months (2 training seasons plus 2 off seasons) bone mineral density of the lumbar spine significantly increased by 4.3%. Therefore, the training induced bone gains were not completely lost in the young adult skeleton. Of the three aforementioned studies, gains in bone mineral content and bone mineral density from training significantly decreased after detraining periods that ranged from short (4-6 months) to longer term (13 months). In the current study, the detraining response differed by skeletal site. At the lumbar spine, bone mineral content regressed to the mean and the 3.5% higher bone mineral content observed after 7 months of jumping was no longer significantly different between groups. However, at the femoral neck, increases in both bone mineral content and bone area in response to 7 months of jumping persisted after 7 months of detraining and were significantly higher than controls after adjusting for changes in growth. We believe that the retention at the femoral neck was due to enhanced growth at this site that did not occur at the lumbar spine. This conclusion is based on our evidence that there were no areal differences at the spine after 7 months of jump training. Both femoral neck bone mineral content and area were significantly higher after detraining in jumpers compared to controls. Given our data that femoral neck area serves as a satisfactory surrogate for cross-sectional area, the higher area observed in the jumpers indicates increased femoral neck dimensions, and thus growth.

We present evidence that a short-term jumping program promotes bone growth at the hip in a population of normal healthy children. Our results suggest that box jumping exercises provide a simple strategy for increasing hip bone mass and may enhance peak bone mass. Continued follow up will corroborate our hypothesis.

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CHAPTER 5

REFERENCE VALUES FOR FAN-BEAM DXA DENSITOMETERS FOR HIP AND SPINE BONE MASS IN CHILDREN

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ABSTRACT

There are limited reference values for hip and spine bone mineral content (BMC) in healthy children that are gender and race specific. To date, reference values are commonly based on chronological age, yet anthropometric variables such as height and weight may better predict skeletal status than age alone. Our aim was to determine the variables that best predict bone mineral content of the hip and spine in order to develop regression equations for healthy, Caucasian children. We assessed 214 apparently healthy, Caucasian pre-pubescent children (118 boys, 96 girls) between the ages of five and 10 (7.4 ± 1.1 yrs; 124.9 ± 8.4 cm; 26.5 ± 6.1 kg). All children were classified as Tanner stage I and were within 20% of body weight for height and age. Bone mineral content (g; BMC) of the left proximal femur (femoral neck and total hip) and lumbar spine (L_1-L_4) were measured using fan-beam DXA (Hologic QDR-4500/A; Waltham, MA). In unpaired t-tests, height and weight were greater in boys than girls ($p < 0.01$ and $p < 0.05$, respectively). In ANCOVA (covariates: age, height, and weight) boys had greater femoral neck, total hip, and lumbar spine bone mineral content than girls ($p < 0.01$, $p < 0.01$, and $p < 0.05$, respectively). In bivariate analysis, age, height, and weight were correlated with femoral neck, total hip, and lumbar spine bone mineral content (r = .68 to .79). In stepwise multiple regression, entering age, height, and weight as predictor variables, height and weight independently predicted femoral neck and total hip bone mineral content in both boys (femoral neck: $R^2 = .48$, total hip: $R^2 = .63$) and girls (femoral neck: $R^2 = .49$, total hip: $R^2 = .65$). Height best predicted lumbar spine bone mineral content in boys ($R^2 = .58$), but both height and weight independently predicted lumbar spine bone mineral content in girls ($R^2 = .54$). However, age did not independently predict bone mineral content at any site in either sex. In conclusion, we developed regression equations that can be used to estimate bone mineral content at the hip and spine in healthy, young Caucasian boys and girls.

Furthermore, based on our results, predictions for skeletal status in prepubertal children should be based on height and weight, not chronological age.

Key words: Normative data, boys and girls, prepubertal, osteoporosis, Caucasian

INTRODUCTION

The development of reference values that are machine specific are necessary due to differences reported across manufactures, instruments, and software (1,2). Of the measurement instruments used to assess bone mass, fan-beam dual energy x-ray absorptiometery (DXA) is the gold standard for measuring hip and spine bone mineral content due to its high precision, fast scan time (less than 60 seconds) and low radiation exposure (reference). To date, few studies have developed reference values for bone mineral content (BMC; g) of the hip and spine for pediatric populations using fan-beam DXA technology. As the use of fan beam DXA technology becomes more prevalent it is necessary to develop reference values from large populations of children that enable researchers and clinicians to ascertain the skeletal health of a growing child. Furthermore, it is important to define the most appropriate prediction variables for skeletal status. To date, most reference values use chronological age as the predictor variable. However, given the important relationship between anthropometric variables and bone acquisition, height and or weight may better predict mineral accrual than chronological age. In this investigation we created regression equations to serve as a tool for estimating hip and spine BMC in healthy, Caucasian, pre-pubescent boys and girls using data collected from a fan beam densitometer (Hologic QDR 4500/A) .

METHODS

Participants

This cross-sectional study utilized the baseline data of 231 children enrolled in a longitudinal exercise intervention study. Of the 231 apparently healthy, prepubertal children enrolled in the longitudinal exercise intervention, 214 (118 boys and 96 girls) children between the ages of 5 and 10 met the inclusion criteria for this investigation of normative data. These children were free of disease and medications that may interfere with bone growth and development, free of orthopedic problems, and were not greater than 20% of the recommended weight for age and height. All children were Caucasian, and classified as Tanner stage I (no signs of secondary sexual characteristics). The parent of each child completed a standard health questionnaire prior to participation in the longitudinal exercise intervention. Information from this questionnaire was used to identify exclusion from this investigation of reference values. Dietary calcium intake was similar between boys and girls (1286.9 ± 65.9 mg for girls and 1241.5 ± 53.3 mg for boys) based on returned questionnaires from 170 of the 214 children (3). Calcium intake values reported for our population are slightly higher than the national average of 1200 mg for children (4). Height and weight were greater in boys compared to girls, with no sex differences for age (Table 5.1).

The 17 children excluded from this study consisted of 14 children not classified as Caucasian, 1 child that exceeded 20% of body weight for age and height, 1 child with bone cancer in both femurs as an infant, and 1 child had bone scans that could not be interpreted. Rationale for excluding these 17 children are as follows: 1) children representing ethnicity's other than Caucasian were excluded since ethnic differences in bone mass have been identified in young children (5-7); 2) children who exceeded the recommended weight for height and age were excluded based on data that report greater bone mass in obese children when compared to normal controls, a difference correlated with body weight (8,9); 3) one child with a history of cancer in both femurs was excluded based on data that have identified lower bone mass, and an increased incidence of osteopenia and osteoporosis in children with a history of childhood cancer (10); and 4) scans with identifiable movement were excluded because DXA machines cannot accurately identify complete bone edges of the scan. The Institutional Review Board at Oregon State University approved this study. All parents and children signed a written informed consent prior to participation.

Anthropometric and secondary sexual characteristics

Height and weight measurements were assessed in light indoor clothing, without shoes. Height was measured using a Seca wall mounted stadiometer (model S-220; Seca, Hanover, MD, USA) to the nearest 0.1 cm. Weight was measured using a Seca electronic weighing scale (model #770; Seca, Hanover, MD, USA) to the nearest 0.1 kg. Tanner stages were used to assess sexual maturation. Parents were given line drawings and written explanations of each developmental stage, using pubic hair in boys and both pubic hair and breast development in girls (11).

Bone measurements

Bone mineral content (g; BMC) of the left proximal femur (femoral neck and total hip) and lumbar spine (L_1-L_4) were examined using dual-energy x-ray absorptiometry, QDR 4500/A (Hologic Inc., Waltham, MA, USA). Bone measurements of the hip and spine have an in-house precision error of 1-1.5% based on adult scans. Precision error for children in our laboratory was not assessed to minimize patient X-ray exposure. All scans were performed using the fast array mode that has a speed of approximately 30 seconds per six inches, and all scans were analyzed using software version 8.26f:3. The proximal femur was scanned with the child in a supine position with the left leg placed in an internally rotated position of 30 degrees using a positioning apparatus provided by Hologic. In the analysis of all hip scans the femoral neck default box of 14 pixels was reduced to ensure that the head of the femur, greater trochanter, and isheum were not included in the analysis, but in all cases was $\geq$ 10 pixels (12). Lumbar spine scans were performed with the child supine with the knees positioned at a 90 degree angle using a semi-soft box provided by Hologic. Lumbar spine scans were analyzed using low-density threshold software. This program locates complete bone edges in individuals with low bone mass, whereas standard adult software fails to detect the complete skeletal region being examined in individuals with low bone mass (13). Bone area and bone mineral density are not reported in this investigation of reference values since, in the growing skeleton bone mineral content most accurately represents the mineral properties of the skeletal region being examined (14). In addition, since bone area and bone mineral content do not increase at similar rates during childhood it is difficult to compare bone mineral density values between children (15).

Statistical analyses

All data were analyzed using SPSS version 9.0. Descriptive characteristics (age, height and weight) and bone mineral content of the left proximal femur (femoral neck and total hip) and lumbar spine (L_1-L_4) are presented by gender. Unpaired t-tests were performed by gender for each descriptive characteristic. One-way (girls vs boys) analysis of covariance (ANCOVA) (covariates: age, height, and weight) analyses was performed to evaluate gender differences for bone mineral content of the femoral neck, total hip and lumbar spine. Simple regression was performed by gender between descriptive characteristics (age, height and weight) and bone variables (bone mineral content of the femoral neck, total hip and lumbar spine). Stepwise multiple regression equations were developed based on predictor variables that entered into the prediction model for bone mineral content of the femoral neck, total hip and lumbar spine. In this analysis, bone mineral content was entered as the dependent variable and age, height, and weight were entered as predictor variables. Prediction equations for bone mineral content of the femoral neck, total hip and lumbar spine were developed based on variables that significantly entered into the stepwise multiple regression analysis. Coefficient of determination values (R^2) are reported for each model. All data are presented as mean ± standard error (SEM).

RESULTS

Bone measurements

Hip: In ANCOVA (covariates: age, height, and weight) boys had greater femoral neck and total hip bone mineral content than girls ($p<0.01$ and $p<0.01$, respectively). (Table 5.1) In simple regression analysis, height had the greatest shared variance for bone mineral content of the femoral neck and total hip in both genders (Table 5.2). In stepwise multiple regression (predictor variables: age, height and weight), height and weight were significant predictors of bone mineral content at the femoral neck and total hip. Age did not enter into the regression equation as an independent predictor of bone mineral content at either the femoral neck or total hip.

Spine: In ANCOVA (covariates: age, height and weight), boys had significantly greater bone mineral content at the lumbar spine than girls ($p<0.01$) (Table 5.1). In simple regression analysis, height had the greatest shared variance for bone mineral content of the lumbar spine in both genders (Table 5.2). In stepwise multiple regression (predictor variables: age, height and weight) height was the most significant predictor of bone mineral content at the lumbar spine in boys, and both height and weight were the most significant predictors of bone mineral content at the lumbar spine in girls. Age did not enter into the regression equation as an independent predictor of bone mineral content at the spine.

Table 5.1. Subject characteristics (mean ± SEM).

	Boys (n=118)	Girls (n=96)	Total (n=214)
Age (yrs)	7.5 ± 1.1	7.2 ± 1.2	7.4 ± 1.1
Height (cm)	126.3 ± 8.1*	123.2 ± 8.5	124.9 ± 8.4
Weight (kg)	27.2 ± 6.2**	25.5 ± 6.0	26.5 ± 6.1
Calcium (mg)	1274.5 ± 422.7	1204.9 ± 419.4	1245.9 ± 419.8
FN BMC (g)	1.88 ± 0.38*	1.61 ± 0.29	1.76 ± 0.37
TH BMC (g)	12.21 ± 2.68*	10.80 ± 2.32	11.57 ± 2.62
LS BMC (g)	20.76 ± 3.78*	18.99 ± 3.86	19.97 ± 3.91

Unpaired t-test between genders, *p< 0.01, **p< 0.05

ANCOVA (covariates: age, height, and weight) between genders, *p< 0.0

Table 2. Prediction equations for femoral neck, total hip, and lumbar spine bone mineral content in boys and girls.

Boys (n=118)

	R^2	SEE	Prediction Equation
FNBMC	.451	.28515	-1.282 + 0.02346*height
	.479	.27898	-1.491 + 0.02346*height+0.01503*weight
TH BMC	.607	1.42616	-20.462 + 0.259*height
	.627	1.39231	-16.567 + 0.208*height+0.09107*weight
LS BMC	.567	2.83709	-23.758 + 0.353*height

Girls (n=96)

	R^2	SEE	Prediction Equation
FN BMC	.464	.21286	-1.282 + 0.02346*height
	.493	.20923	-0.918 + 0.01835*height + 0.01042*weight
TH BMC	.627	1.69050	-15.902 + 0.217*height
	.648	1.65287	-13.124 + 0.178*height + 0.07944*weight
LS BMC	.466	2.49977	-19.265 + 0.310*height

DISCUSSION

We have shown that in a large population of healthy, young Caucasian children, height and weight, not age, best predict BMC at the hip and spine. From these data, we develop prediction equations based on height and weight for hip and spine BMC using a fan beam densitometer.

Our study has several strengths. First, we report sex and race specific reference values and prediction equations from fan beam technology for hip and spine BMC in a large cohort of healthy, Caucasian children. Warner and coworkers have reported reference values and prediction equations and coworkers for a small cohort of Caucasian children between the ages of 6 and 18 years using a pencil beam densitometer (Hologic, 1000/W) (15). However, since significant differences in bone values have been reported between pencil beam and fan beam densitometers it is necessary to have technology-specific reference values and prediction equations (1,16). Second, our prediction equations will permit researchers and clinicians to predict bone mineral content at the hip and spine in children between the ages of five and 10 years based on anthropometric variables (height and weight) that are easy to measure in the lab or clinic. Third, we report regression equations for the lumbar spine using low-density threshold software that accounts for low mineral content in a pediatric population. For an accurate assessment of bone mass in children, it is necessary to use this software to ensure that complete vertebral bone edges are detected (13).

It is important to note limitations of our investigation. First, we recognize that we have only examined children between the ages of five and 10 who are of Caucasian descent. Future studies should extend the ages of assessment and include children of diverse ethnicities. In addition the age range we examined included only prepubertal children. This may have limited our ability to develop regression equations with a higher coefficient of determination. Second, based on differences that have been reported between machine types, manufacturers and software, our regression models should only be used for Hologic fan-beam densitometers.

A limited number of studies have reported reference values for BMC at the hip and spine in prepubertal children using fan beam technology (8,15,17-20). DeSchepper and coworkers were the first to report reference values for the lumbar spine (L_{2-4}) for growing children between 1 and 18 years using dual photon absorptiometery (manufacturer: Novo Industry BMC-Lab 2)(8). In that investigation 136 children were tested, and of these 78 children had a recent fracture of the peripheral skeleton, and 33 children had minor orthopedic problems. Both height and weight were highly correlated with BMC at the lumbar spine in both genders. However, no correlation coefficients were reported. Proesmans and coworkers (17) evaluated lumbar spine (L_{2-4}) BMC in 97 healthy Caucasian children between the ages of 3 and 14 using dual photon absorptiometry (manufacturer: DP4; Lunar). Height and weight significantly predicted BMC at the lumbar spine (R^2=.86) in both genders. The coefficient of determination reported in this study was higher than those reported in our study for the spine. This may be due to the larger age range studied by Proesmans and coworkers. Warner and coworkers (15) established prediction equations for lumbar spine BMC based on age, body size, and pubertal development in 58 healthy boys and girls between the ages of 6 and 18 using a Hologic QDR 1000/W pencil beam densitometer. That investigation contained a limited number of subjects within each gender; however it did include multiple developmental stages. The prediction equations developed by Proesmans and coworkers (17) and Warner and coworkers (15) for lumbar spine BMC are not appropriate for fan beam densitometers due to differences in technologies. Del Rio and coworkers (18) evaluated lumbar spine BMC using dual photon absorptiometry (manufacturer: Lunar (DPX-L densitometer) in 471 healthy white Mediterranean Spanish children and adolescents (256 boys and 215 girls) between the ages of 3 months and 21 years. Significant correlations were reported between lumbar spine BMC and age, height, and weight, but no prediction equations were reported. This investigation included a nice age rage on children from an ethnic background other than Caucasian.

The equations we have developed provide hip and spine reference data specifically for pre-pubertal Caucasian children evaluated by fan-beam technology. These norms can be used by researchers and clinicians to assess skeletal health of pediatric populations and may also be integrated into databases available for fan-beam densitometers.

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CHAPTER 6

BONE RESPONSE TO A SHORT TERM EXERCISE PROGRAM IS SIMILAR REGARDLESS OF CALCIUM INTAKE

Robyn K. Fuchs , Christine M. Snow and Connie Weaver

ABSTRACT

Low calcium intake during childhood is linked to an increased risk of childhood fractures and osteoporosis in adulthood. Both weight-bearing exercise and calcium supplementation have been shown to be effective strategies for improving bone mass in the growing skeleton. However, the interaction between calcium intake and exercise during childhood is poorly understood. Our aim was to examine the permissive role of calcium and the bone response to mechanical loading in prepubertal children that completed a 7-month exercise intervention. Results are based on 84 children who completed the intervention and had complete dietary information. Bone mineral content (BMC; g) of the left proximal femoral neck and lumbar spine (L1-4) were assessed by dual-energy x-ray absorptiometry (DXA; Hologic 4,500/A). Average dietary calcium intake (mg) was calculated based on information derived from the Harvard Medical Youth Food Survey at baseline and post-testing. There were no group differences for average calcium intake, and 73% percent of our population met or exceeded the recommended intake for their age group (5-8 years, 800mg, 9-10 years, 1,200mg). In bivariate correlation analyses, there was no relationship between average dietary calcium and baseline BMC at the femoral neck and lumbar spine. In addition, there was no relationship between average dietary calcium and 7-month changes in BMC at the femoral neck and lumbar spine. In partial correlation analysis, controlling for changes in height and weight and baseline bone values there was no relationship between the bone response to exercise training and calcium intake. Our data suggest that for our group of children, calcium did not influence the bone response to exercise training at two sites of loading, the femoral neck and lumbar spine. However, those children with low intakes of calcium may be compromising the attainment of optimal peak bone mass despite the skeletal benefits of high-impact jumping. This conclusion needs to be further examined in randomized controlled trials of both calcium and exercise.

INTRODUCTION

Osteoporosis is dependent on both the amount of peak bone mass attained in ones lifetime and the rate of bone loss as we age. In an effort to reduce fractures related to osteoporosis and low bone mass, the most cost-effective strategy is to improve peak bone mass (Fassler, 1995; Bachrach, 2001). This may be accomplished by encouraging health habit such as engaging in regular weight bearing physical activity, or ingesting optimal amounts of calcium. The efficacy of these strategies has been demonstrated in numerous longitudinal intervention trials (Fuchs et al., 2001; Heinonen et al., 2000; Mackelvie et al., 2001; Mckay et al., 2000; Morris, 1997; Petit, 2002; Johnston et al., 1992; Lee et al., 1994); however, there are no reported data that have examined the interaction between exercise and calcium in a randomized trial.

If exercise is to be used as a strategy to improve peak bone mass it is necessary to determine the calcium requirements for active children. In cross-sectional and observational reports of the growing skeleton, physical activity is reported as a more significant contributor to bone mass than calcium, even despite low calcium intake. However, intakes below 1,000 mg may result in lower peak bone mass attainment (Anderson 2001; Weaver, 2000). In a longitudinal exercise intervention by Specker and coworkers (1999) of young infants between 6-18 months, the bone response to exercise was lower in those children with sub-optimal intakes of calcium. The aim of this investigation was to examine the permissive role of calcium on the bone response to mechanical loading in a group of children that engaged in a 7-month, high-impact jumping program.

SUBJECTS AND METHODS

This investigation was an ancillary study designed to examine the permissive role between dietary calcium intake and the bone response to jump training at the hip and spine in prepubertal children. Children represented in this study completed a 7-month exercise intervention program that was incorporated into the curriculum of an elementary school in Corvallis, OR. The exercise intervention consisted of two groups, jumpers and stretchers. Those children from the jumping group completed 100 jump trials off a 61 cm box, 3 times per week while the control group performed non-impact flexibility exercise. Details of the exercise intervention have been reported previously (Fuchs, Bauer, & Snow, 2001).

Eighty-nine children (45 jumpers and 44 controls) completed the intervention and had ethnic backgrounds as follows: 87 Caucasian, 1 Asian girl and 1 Caucasian-Hispanic girl. Of these, 84 Caucasian children (40 jumpers and 44 controls) had complete nutrition information and were included in this investigation for analysis. Details on exclusion criteria, and methods of informed consent have been reported previously (Fuchs, Bauer, & Snow, 2001).

Height and weight were measured in light indoor clothing without shoes. Height was recorded to the nearest 0.1 cm using a wall-mounted stadiometer (model S-220; Seca, Hanover, MD, USA) and weight was recorded to the nearest 0.1 kg using a Seca electronic weighing scale (model #770; Seca). Body fat was estimated using gender specific prediction equations formulated by Williams and co-workers (Williams et al., 1992). Tanner stages were used to assess sexual maturation (Tanner & Whitehouse, 1976. Parents were given line drawings and written explanations of each developmental stage, using pubic hair in boys, and both pubic hair and breast development in girls. A researcher knowledgeable with the Tanner stage criteria was available to answer questions.

BMC (g) and bone area (BA: cm^2) of the left proximal femoral neck and lumbar spine (L_{1-4}) were evaluated by dual energy X-ray absorptimetry (Hologic QDR/4500-A; Waltham, MA). Bone measurements of the hip and lumbar spine have an in-house precision error of 1-1.5% based on adult scans. Information on positioning and analysis of the hip and spine scans has been reported previously (Fuchs, Bauer, and Snow, 2001).

Physical activity was assessed by parent and child using a self-report physical activity questionnaire developed for older children and adolescents (Slemenda et al., 1991), and dietary calcium intake was obtained using information obtained form the Harvard Medical School Youth Diet Survey. Dietary calcium is reported as an average of reported baseline and post-testing values. Detailed information on these questionnaires has been reported previously (Rockett et al., 1995).

All data were analyzed using SPSS version 9.0 (SPSS, Chicago, IL, USA). Univariate analysis of variance (ANOVA) was used to examine group differences between the jumping and control groups for anthropometric characteristics at baseline and post-testing, and average dietary calcium intake. The relationship between average calcium intake, baseline bone values (femoral neck and lumbar spine BMC), and 7-month change scores (femoral neck and lumbar spine BMC) were examined using Pearson's bivariate correlation analysis. A partial correlation analysis was performed between average dietary calcium intake and 7-month change scores, controlling for changes in height and weight and initial bone values. A Bonferroni adjustment was used for all correlation analyses to control for type I error. All data are presented as means ± SD.

RESULTS

Jumpers and controls were similar at baseline and the completion of the intervention for all anthropometric characteristics (Table 6.1). Both groups had similar gains in height, weight and body fat. All children were classified as Tanner stage I (prepubertal) at baseline and post-testing.

Table 6.1. Baseline and post intervention anthropometric characteristics by group.

	Jumpers n=40	**Controls** n=44
Age (years)		
Baseline	7.5 ± 0.16	7.6 ± 0.17
Post	8.1 ± 0.16	8.2 ± 0.17
Height (cm)		
Baseline	125.1 ± 1.3	126.8 ± 1.2
Post	128.7 ± 1.3	129.9 ± 1.2
Weight (kg)		
Baseline	27.1 ± 0.8	28.0 ± 1.0
Post	28.8 ± 0.8	29.7 ± 1.1
Body Fat (%)		
Baseline	19.5 ± 0.9	20.7 ± 0.9
Post	20.1 ± 0.9	20.5 ± 1.1

Values reported as mean ± SD. ANOVA, $p > .05$

In analysis of variance (ANOVA) there were no group differences for average dietary calcium intake (jumpers: 1249.3 ± 374.9 mg and controls: 1296.0 ± 394.7 mg). The minimum and maximum reported values were 500 mg/day and 2,000 mg/day, respectively. 73% of our group had dietary intakes that met or exceeded the recommended intake values for their age group. (Add DRI values, what the requirements are.

Pearson's correlation coefficients were computed separately, by group between average dietary calcium, baseline bone values, and 7-month change bone values. Using the Bonferroni approach to control for Type I error across the eight correlations, a p-value of less than .006 was required for significance. The results of the bivariate correlation analysis are presented in Table 6.2 by group. None of the correlations were statistically significant for both the jumping and control group.

Table 6.2. Correlations between dietary calcium and 7-month difference scores for femoral neck and lumbar spine bone mineral content by group.

	Jumpers (n=40)	**Stretchers (n=44)**
	Calcium (mg)	**Calcium (mg)**
FN BMC Baseline	-.063	.175
LS BMC Baseline	-.191	.175
FN BMC Change Score	-.161	-.103
LS BMC Change Score	.055	.205

Bivariate correlations, $p > 0.05$.

Abbreviations: FN; femoral neck, LS; lumbar spine, BMC; bone mineral content.

Partial correlations were computed by group between average dietary calcium and 7-month changes in BMC of the hip and spine, controlling for changes in height and weight, and initial bone values. Using the Bonferroni approach to control for Type 1 error across **4** correlation's, a p-value of less than .012 was required for significance.

The results from the partial correlational analysis are presented in table 6.3. None of the correlations were statistically significant for both the jumpers and controls.

Table 6.3. Partial Correlations between average dietary calcium and 7-month difference scores for femoral neck and lumbar spine bone mineral content for both the jumping and control group.

	FN BMC Change Score		**LS BMC Change Score**	
	Jumpers	**Controls**	**Jumpers**	**Controls**
Calcium (mg)	-.107	-.108	.062	.186

Partial correlations, p >.05.

Abbreviations: FN; femoral neck, LS; lumbar spine; BMC; bone mineral content.

DISCUSSION

We report that children who participated in 7-months of jump training responded similarly to an intervention of high-impact loading despite differences in calcium intake. It is important to note that 73% of our sample met or exceeded the daily-recommended intake for calcium for their age group. Therefore, a clear relationship between daily dietary calcium and the bone response to training was difficult to ascertain.

Calcium functions as a threshold nutrient. This means that above a certain level, increased intake will have no further skeletal benefits (Matkovic, Fontant, Tominac and Goel, 1990; Weaver & Heany, 1997). Dietary intakes of calcium between 1,300 mg/day and 1,500 mg/day are required for maximal calcium retention based on results from calcium balance studies (reference). Intakes below 1,000 mg/day may result in the attainment of lower peak bone mass (Anderson, 2001; Weaver, 2000). However, for a growing child who engages in regular weight-bearing physical activity, intakes below 1,000 may allow for sufficient growth (Welten et al., 1994; Ruiz et al., 1995). In our group, 61 children meet the recommended daily intake values for their age group, 38 children were consuming calcium at or above threshold levels, and only 10 children had reported intakes below 800 mg/day. Although we report no relationship between calcium intake and changes in bone in both the jumping and control groups, those children who were below the recommended level for calcium intake may be compromising their optimal peak bone mass attainment. In addition, the children in our study have not reached a period of accelerated growth.

To date, no randomized trials have reported data examining the interaction between exercise and the bone response to training. This is an important question to address in order to determine dietary requirements for active children, and to determine if calcium plus exercise results in a synergistic or additive bone response. For example, a child who participates in regular physical activity may require more, or less calcium to achieve optimal mineral retention. Data regarding the relationship between calcium intake, physical activity, and bone have mixed results, with some cross-sectional and observational reports suggesting that weight-bearing exercise may override inadequate calcium; while others suggest that adequate calcium intake is required in order to elicit training induced bone gains. Ruiz and co-workers (1995) reported sport activity to be a stronger predictor of lumbar spine and femoral bone mineral density (BMD; g/cm2) than calcium intake in girls and boys between the ages of 7 and 15.3 years. In this study physical activity was a stronger predictor even though 63% of the subjects had calcium intakes below 1000 mg. Welten and co-workers (1994) examined the relationship between nutrition, physical activity, and lumbar spine BMD in men and women between the ages of 13 and 28. Physical activity and body weight were reported as the strongest predictors of bone mass at the lumbar spine. Calcium intake did not enter into the regression model as a significant predictor. Valimaki and coworkers performed a prospective cohort study examining BMD of the lumbar spine and femoral neck in men and women after 11 years of follow-up. 264 subjects between the ages of 9 and 18 were initially enrolled in the study, and were 20-29 years of age at the time of follow-up. Exercise was found to be the strongest predictor of femoral BMD in women, and lumbar spine BMD in men. However, in a separate analysis, women who consumed between 800-1200 mg of calcium had higher femoral neck BMD than women with intakes less than 800 mg. Of the exercise intervention trials reported to date in children, the relationship between calcium and the bone response to exercise training has only been examined in one other study besides ours. In an exercise intervention trial by Specker and coworkers (1999), infants between 6-18 months old were randomized into a one year activity program of bone loading exercises. All infants were given infant formula to minimize differences between groups for calcium intake. After one year of training there were no group differences for whole BMC. However, it was speculated that children with low calcium intake had reduced BMC after performing the bone loading exercises. It was not clear why there were significant differences in calcium intake since infant formula was provided to ensure equivalence for calcium intake. Results from the aforementioned studies suggest that weight-bearing exercise exerts a positive influence on bone, and this response may be mediated by differences in calcium intake. We must await results from randomized controlled trials examining the interaction between calcium and exercise to make these findings more definitive.

It is important to address the strengths and limitations of this study. First, we used a food questionnaire specifically designed for the longitudinal assessment of dietary intake (Rocket et al., 1995). This questionnaire included common foods consumed by children and adolescents, and it allows the parent/child to add additional food items to the questionnaire. A parent helped their child complete this questionnaire to ensure accurate reporting of data; however some parents had difficulties recalling dietary information for the past 6-months, some parents did not spend adequate time completing the questionnaire, and some parents had to guess on certain food items. This may have resulted in skewed values for some of our subjects. Second, we did not perform a randomized intervention trial designed to examine the interaction between exercise and calcium. This was an ancillary question to provide preliminary information for the relationship between the bone response to exercise training and calcium intake. Third, the dietary calcium values include calcium from all food sources and supplementations. We did not receive a report on the specific types of food sources that dietary calcium was coming from; however this is an important question to address in order to evaluate the types of calcium sources that may be most beneficial. Lastly, due to the high reported calcium intake values for the children in our group this may have prevented us from finding a relationship between calcium intake and the bone response to training.

In conclusion, there is strong evidence that both weight-bearing physical activity and calcium intake are necessary for building a strong skeletal foundation. Results from our study suggest that the bone response to high-impact training was not related to average dietary calcium intake. However, those children with low intakes of calcium may be compromising the attainment of optimal peak bone mass despite the skeletal benefits of high-impact jumping. This conclusion needs to be further examined in randomized controlled trials of both calcium and exercise.

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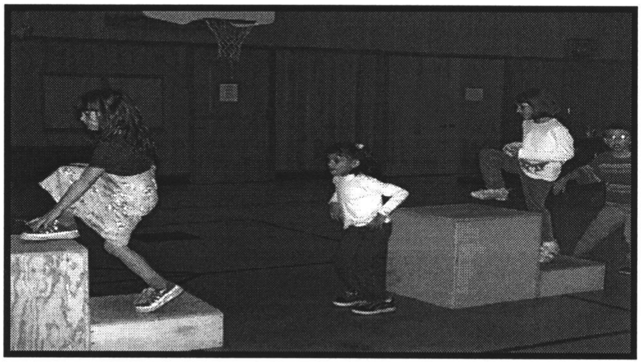
CHAPTER 7

CONCLUSIONS



Results form our 7-month intervention trial in prepubertal children provides evidence that a simple jumping program of 300 jumps/week at a load magnitude of 8 body weights promotes bone growth at the hip and spine, and thus may enhance peak bone mass. Specifically, children in the jumping group had 4.5% and 3.1% greater bone mineral content at the hip and spine, respectively, compared to controls, and 2.9% greater bone area at the hip compared to controls. The exercises proved to be safe, as no injuries were reported during the intervention period, and no children withdrew from the study as a result of pain or injury from the jumping exercises. The jumping program we designed would allow for easy incorporation into physical education programs, with the exercises taking only 10 minutes to perform.

Results from our detraining intervention, that commenced immediately after the completion of the 7-month training intervention provide encouraging evidence that jumping may enhance growth at the hip. Specifically, jumpers maintained 4% greater bone mineral content and 4% greater bone area at the femoral neck than controls, 7-months after the high impact jumping exercises were withdrawn. This finding is promising, especially since training induced bone gains from prospective training interventions of the mature skeleton show that bone mass reverts towards baseline values soon after training is discontinued (Winters & Snow, 2000; Dalsky et al; 1988). Continued long-term follow-up of these children will enable us to determine if the benefits of exercise persist through the adolescent growth spurt. The children in our study had not reached the age at which maximal bone mineral is retained.

Due the large number of subjects recruited for our intervention trials we were able to develop regression equations for bone mass at the hip and spine for children between the ages of 5 and 10. The equations we have developed provide hip and spine reference data for pre-pubertal Caucasian children who are evaluated by fan-beam DXA technology. These norms can be used by researchers and clinicians to assess skeletal health of pediatric populations and may also be integrated into databases for Hologic (4500/A) fan-beam densitometers. Our prediction equations would be improved by including a broader age range of children. In addition, height and weight may not be the most appropriate variables to use in the development of prediction equations, especially since a small age range of children were examined. Additional variables such as sitting height and Tanner stage would be useful predictor variables to include in the development of regression equations.

Results from our ancillary study examining the permissive role of calcium suggests that jumping, a high-impact activity may allow the skeleton to increase mineral despite sub-optimal calcium intake levels. However, it is important to note that a majority of the children in our sample were calcium replete. In order to achieve optimal peak bone mass it is necessary for parents and educators to encouraged lifestyles habits that include a healthy balance of both weight-bearing exercise and adequate dietary nutrients, such as calcium. It is suggested that active children may require higher intakes of calcium to meet skeletal demands. However, at this time there are no clear guidelines set for children with varying activity levels. It would be usefully to conduct a calcium balance study in active versus inactive children. If active children require more calcium it would then be necessary to revise the current dietary guidelines. In addition, it would be useful to conduct an intervention trial examining the relationship between calcium intake and exercise in the growing skeleton. Our trial suggests that there is no relationship between gains in bone mass from exercise training and dietary calcium; however other trials suggest that sub-optimal calcium may be detrimental to the skeleton. A randomized controlled trial would allow for more definitive conclusions to be made regarding the interaction between exercise and dietary calcium in growing children.

Osteoporosis is a complex disease that has been characterized as a pediatric disorder that manifests itself during adulthood. The amount of bone mineral an individual acquires during childhood and adolescence is a key determinant of adult skeletal health because peak bone mass is a primary predictor of fractures in later life. The results form our exercise intervention trial have important implications for the prevention of osteoporosis. We report evidence that a simple exercise program may enhance peak bone mass at two clinically relevant fracture sites, the hip and spine. In addition, our results suggests that bone gained from exercise training is maintained at the hip. This simple exercise may be included into physical education programs as a preventive strategy for osteoporosis. Long-term follow-up of these children will allow us to identify if these gains are retained after the adolescent growth spurt.

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APPENDICES

APPENDIX A

ADDITIONAL PEER REVIEWED MANUSCRIPTS

Quantifying force magnitude and loading rate from drop landings that induce osteogenesis. Bauer, JJ., Fuchs, RK., Smith, GA., and Snow, CM. Journal of Applied Biomechanics,17:2, 2001

Bone gains and losses follow seasonal training and detraining in gymnasts. Snow, CM., Williams, DP., LaRiviere, J., Fuchs, RK., and Robinson, TL. Calcified Tissue International., 69:7-12, 2001.

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Quantifying Force Magnitude and Loading Rate From Drop Landings That Induce Osteogenesis

Jeremy J. Bauer, Robyn K. Fuchs, Gerald A. Smith, and Christine M. Snow

Drop landings increase hip bone mass in children. However, force characteristics from these landings have not been studied. We evaluated ground and hip joint reaction forces, average loading rates, and changes across multiple trials from drop landings associated with osteogenesis in children. Thirteen prepubescent children who had previously participated in a bone loading program volunteered for testing. They performed 100 drop landings onto a force plate. Ground reaction forces (GRF) and two-dimensional kinematic data were recorded. Hip joint reaction forces were calculated using inverse dynamics. Maximum GRF were 8.5 ± 2.2 body weight (BW). At initial contact, GRF were 5.6 ± 1.4 BW while hip joint reactions were 4.7 ± 1.4 BW. Average loading rates for GRF were 472 ± 168 BW/s. Ground reaction forces did not change significantly across trials for the group. However, 5 individuals showed changes in max GRF across trials. Our data indicate that GRF are attenuated 19% to the hip at the first impact peak and 49% at the second impact peak. Given the skeletal response from the drop landing protocol and our analysis of the associated force magnitudes and average loading rates, we now have a data point on the response surface for future study of various combinations of force, rate, and number of load repetitions for increasing bone in children.

Key Words: ground reaction forces, inverse dynamics, hip joint, high impact, jumping, osteoporosis

Introduction

Increasing peak bone mass is a primary goal for osteoporosis prevention (NIH Consensus Conference, 2000). Maximizing bone gain during childhood through physical activity may be the most effective way to increase peak bone mass (Slemenda, Reister, Hui, et al., 1994). Thus, developing strategies for enhancing bone accretion during childhood is central to combating osteoporosis (Fassler & Bonjour, 1995).

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Mechanical loading via physical activity with both high forces and high loading rates has been shown to be osteogenic at the hip. Athletes who participate in high impact activities such as gymnastics tend to have a greater bone mineral density at the hip and spine compared to athletes who compete in relatively lower impact activities such as running and swimming (Taaffe, Robinson, Snow, & Marcus, 1997). Gymnasts have been reported to have up to 35% greater bone mineral density at the hip than runners. In addition, the high impact stimuli that gymnasts are exposed to has been reported to counter any bone loss due to amenorrhea and oligomenorrhea (Robinson, Snow-Harter, Taaffe, et al., 1995). Ground reaction forces from gymnastics are 10–18 times body weight whereas those from running are 2–3 times body weight (McNitt-Gray, 1993; Munro, Miller, & Fuglevand, 1987). In addition, forces are delivered more quickly during gymnastic landings than during running.

Although there have been interventions that include a variety of exercises to augment bone mass in children, to our knowledge none have quantified all the forces associated with one complete exercise session (Bradney, Pearce, Naughton, et al., 1998; McKay, Petit, Schutz, et al., 2000; Morris, Naughton, Gibbs, Carlson, & Wark, 1997). In addition, a primary issue with the multidimensional nature of the exercise interventions to date is that, even if forces had been measured, given the variety of the exercises included in these interventions, it is not possible to identify the contribution of each exercise to the osteogenic response. Calculating the forces of specific activities associated with changes in bone mass will allow appropriate design of exercise prescription for preventing osteoporosis.

Using gymnastics landings as a model, Fuchs, Bauer, and Snow (2001) developed a program using only one exercise to increase bone mass in growing children. After 7 months the jumpers exhibited a 5.6% greater increase in bone mineral content at the femoral neck than did the control group. Although a bone response was clear, the osteogenic mechanisms involved were not addressed. In particular, the forces from the drop landings and their potential to increase or decrease across trials, as well as the rate of loading, were not investigated. Thus, the purpose of this study was to describe the force characteristics of prepubescent children engaged in drop landings and answer the following research questions: (a) What are the ground and hip joint reaction forces from drop landings? (b) Do the forces change in magnitude across repeated load applications? (c) What is the average loading rate associated with drop landings?

Methods

Thirteen prepubescent children (8 boys, 5 girls, age 9.3 ± 0.7 yrs) who had previously completed drop landings over a 7-month period as part of an exercise intervention to increase bone mass participated in this research. All were prepubertal (Tanner Stage 1), as assessed by the children themselves and their parents pointing to the line drawing of the pubertal stage that represented the child at the time of testing (Tanner & Whitehouse, 1976). This study was approved by the Oregon State University Institutional Review Board. Parents and children provided written informed consent.

Each child performed 100 drop landings onto a force plate from a height of 61 cm. After each landing, participants returned to the 61-cm height by first stepping onto a 30-cm high box, then to the 61-cm high box. Each child was allowed to proceed through the 100 trials at his or her own pace.

The children landed on a 0.60 × 0.40-m force platform (Kistler, 9281B) with both feet. Ground reaction forces (GRF) were collected for 950 ms at 1000 Hz. Prior to each landing, an A/D board in a computer triggered the collection of force data when a beam of light entering a photo resistor 10 cm above the force plate was disrupted by each child's feet. Triggering the force collection before contact provided data where the measured force should be zero. If the precontact data were nonzero, then these values were subtracted from every force value in the respective trial to correct for a small amount of drift in the force plate transducers. A trial was considered acceptable when both feet were completely on the force platform from initial contact to standing at rest. Trials were excluded if the child made contact with any surface other than the force platform upon landing, or if the computer was not triggered to record GRF data before initial contact. In all, 94% of the 1,300 trials were included in the analyses.

Asymmetry between legs in the magnitude of ground reaction forces upon landing has been reported to be up to 14.8% (Schot, Bates, & Dufek, 1994). An ideal assessment of the kinetics of each leg upon landing would require two force plates or landing on the force plate with one foot on and one foot off. However, for the purpose of this study it was assumed that each leg was subjected to exactly half the total measured ground reaction force. It was thought that the children would not proceed through the jumps naturally if they were required to target half of the force plate.

Average loading rate was determined by dividing the force at Peak 1 by the time to Peak 1 (Crossley, Bennell, Wrigley, & Oakes, 1999). A common method for calculating average loading rate in running uses the portion of the force trace starting from 50 N up to 1 body weight + 50 N. While this is reasonable when using a GRF trace from running, this method would neglect a large portion of the slope in the initial force peak from drop landing since the magnitude at the first peak is much higher than 1 body weight + 50 N.

Figure 1 — Jump sequence showing reflective marker placement.

Six 1-cm diameter reflective markers made from 3M retro-reflective tape were placed on the left side at the following anatomical sites: heel, 5th metatarsal head, lateral malleolus (ankle), knee joint center, greater trochanter (hip), and acromion process (shoulder) (Figure 1). The left side of the body was chosen because previous bone mass measurements were taken on the left proximal femur. Two-dimensional kinematic data from sagittal plane motion were collected at 250 Hz using a high-speed digital camera (Redlake Corp., Morgan Hill, CA; model 1000/s). To synchronize the kinematic data with the force data, a pulse was produced by a digital output from the A/D board at the instant the force plate was triggered. The pulse produced a white square in the upper left corner of the video image. To ensure that there was no delay between triggering of the force plate and output of the synchronizing pulse to video, the output of the photo resistor on an oscilloscope screen was also recorded on the right side of the video image. Since each child was allowed to proceed at his or her own pace, it was not possible to record every trial with the camera due to the nature of the recording system. An attempt was made to capture as many trials as possible for each child. The number of trials recorded on video ranged from 11 to 22 across subjects.

Peak 5 motion analysis software (Peak Performance Technologies, Englewood, CO) was used to digitize and filter the digitized displacement data. Displacement data were filtered using a 4th order Butterworth recursive digital filter at a cutoff frequency of 6 Hz to exclude high frequency noise resulting from the Peak 5 auto-digitizing process. This process involved a double pass, forward and backward, to cancel out any phase distortion. Despite the prefiltering at 6 Hz, differentiation magnified the remaining noise substantially. Therefore, to remove high frequency noise from the acceleration data, we used a 4th order Butterworth recursive digital filter with a cutoff frequency range of 23–28 Hz to remove high frequency noise from the velocity data. This cutoff frequency was calculated for each segment and direction via residual analysis (Winter, 1990). The method of inverse dynamics used to calculate joint reaction forces is based on segment position and acceleration data, both of which must be optimized to reduce any existing noise. Therefore, the general approach to the signal analysis was to filter twice. Filtering displacement data followed by filtering derivatives has been discussed by Giakas and Baltzopoulos (1997).

The final step in the calculation of joint reaction forces involved merging the kinematic data with the force data. In order to use all of the 1000-Hz force data with the 250-Hz kinematic data, we employed linear interpolation to determine kinematic data between samples, effectively creating a 1000-Hz kinematic data set. Body segment parameters specific to children were used to calculate segment percent of total body mass and segment center-of-mass (Jensen, 1986).

The model for calculating joint reaction forces is illustrated using three rigid segments (Figure 2). Prediction equations for the hip reaction force components and resultant reaction force components were used (Equations 1–3).

$$R_x = -F_x + m_f \cdot a_{fx} + m_s \cdot a_{sx} + m_t \cdot a_{tx} \tag{1}$$

$$R_y = W_f + W_s + W_t - F_y + m_f \cdot a_{fy} + m_s \cdot a_{sy} + m_t \cdot a_{ty} \tag{2}$$

$$R = \sqrt{R_x^2 + R_y^2} \tag{3}$$

Changes in maximum vertical ground reaction forces across 100 trials and changes in maximum resultant hip joint reaction forces across 100 trials, within each subject and for the group, were analyzed via simple linear regression. In each case (i.e., GRF v Trial # or HJRF v Trial #), maximum force was assigned as the response variable and trial number was assigned as the explanatory variable. The slope of the regression line

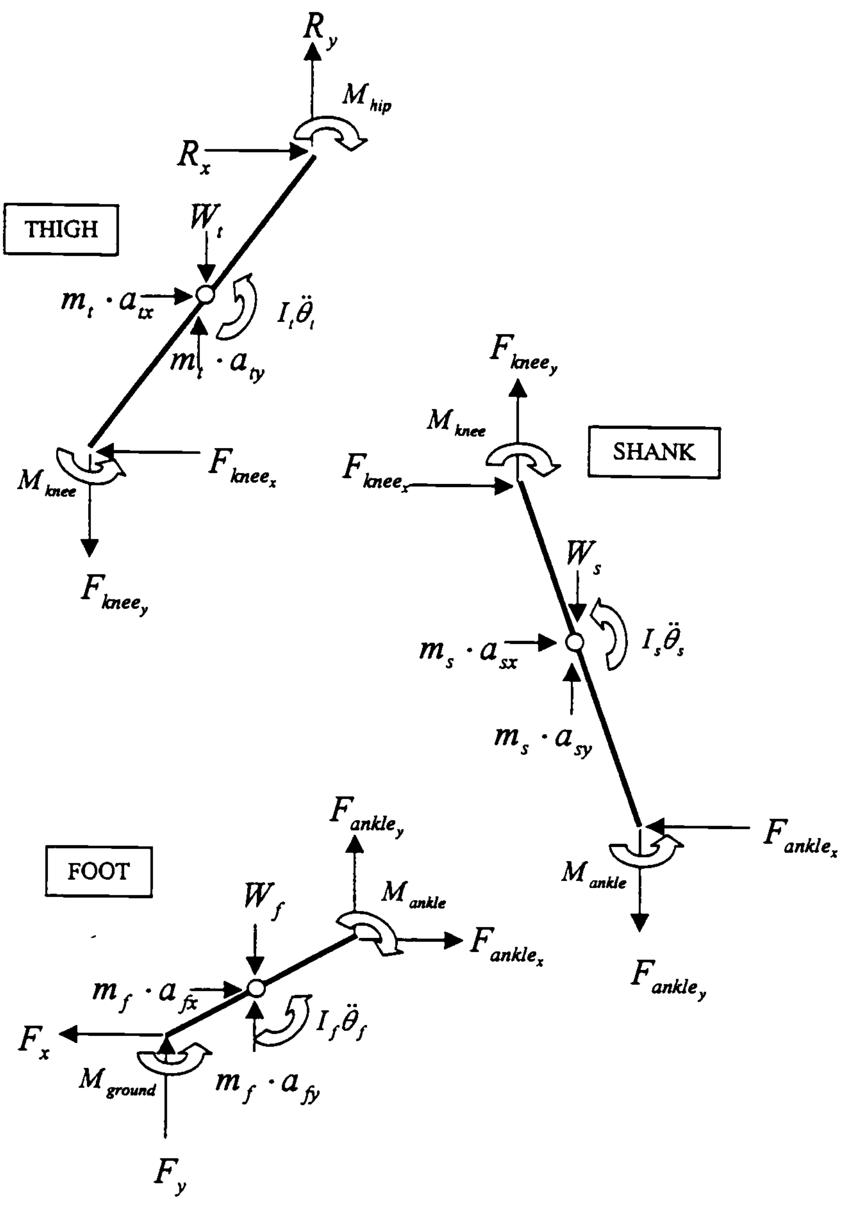

Figure 2 — Joint reaction force free-body diagrams.

a	**Acceleration of the segment center of mass.**
m	**Acceleration of the segment.**
F_x	**Horizontal ground reaction force.**
F_y	**Vertical ground reaction force.**
R_x	**Horizontal hip joint reaction force.**
R_y	**Vertical hip joint reaction force.**
R	**Resultant hip joint reaction force.**
W	**Weight of the segment.**
M	**Moment at the ground.**
I	**Moment of inertia of the segment.**
$\ddot{\theta}$	**Angular acceleration of the segment.**

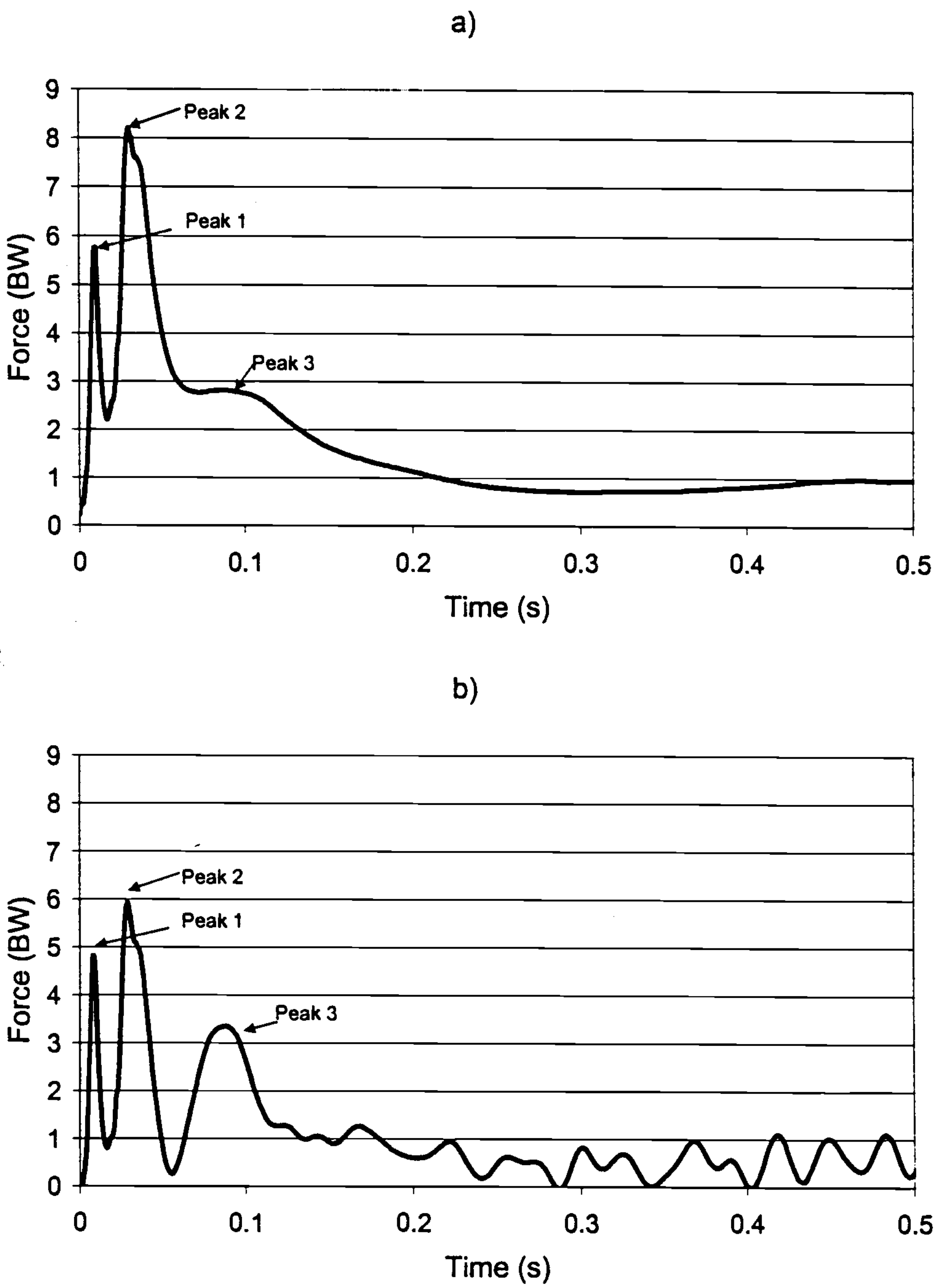

Figure 3 — Typical traces from (a) vertical ground reaction forces, and (b) resultant hip joint reaction forces.

for each subject and for the group was used to determine whether forces changed across trials (i.e., if slope did not differ significantly from 0, then maximum reaction forces did not tend to increase or decrease across 100 trials). Statistical significance was set at $p < 0.05$. SPSS version 9.0 was used to compute all statistics (SPSS Inc., Chicago).

Results

The typical force trace observed during landing has three distinguished peaks consistent with measurements from other landing literature (Devita & Skelly, 1992; Dufek & Bates, 1990). The first peak represents toe contact; the second peak, with generally the greatest magnitude, is for heel contact; the third peak represents active muscle activation slowing the descent of the center of mass (Figure 3). While no EMG data were recorded during the landings, sharp peaks in a force trace have been explained as a result of passive reflexive muscle stiffness resulting from rapid stretching of the plantar flexors (Dyhre-Poulsen, Simonsen, & Voigt, 1991). An active peak force, due to voluntary muscular contraction in braking movements, usually follows the initial passive peaks.

Force magnitudes were determined for the first two impact peaks in both the ground reaction force trace and the hip joint reaction force trace (Table 1). GRF characteristics did not remain consistent for all children across 100 trials. Five of the 13 children had statistically significant (non-zero maximum GRF regression line slopes) changes in maximum ground reaction forces across 100 trials (Figure 4). Four individuals who had changes across trials increased maximum ground reaction forces as trial number increased ($p < 0.001$), and one child decreased maximum ground reaction forces as trial number increased ($p < 0.02$). As a group, maximum ground reaction forces did not change across trials ($p = 0.11$). Maximum resultant hip joint reaction forces did not change significantly across trials for any child or for the group.

Table 1 Summary Force Characteristics

	Peak 1	Peak 2
Vertical GRF (BW)	5.6 ± 1.4	8.5 ± 2.3
Resultant HJRF (BW)	4.7 ± 1.4	5.7 ± 1.9
Avg loading rate (BW/s)	472 ± 168	

Note: GRF = Ground reaction force; HJRF = Hip joint reaction force; BW = Body weight

Discussion

Our aim was to describe the force magnitudes and average loading rates from drop landings associated with hip osteogenesis in children. We addressed the following research questions: (a) What are the ground and hip joint reaction forces from drop landings? (b) Do they change in magnitude across repeated load applications? (c) What is the average loading rate associated with drop landings? Upon landing, two sharp force peaks were apparent in both the ground reaction and hip joint reaction force profiles. Attenuation of the ground reaction forces to the hip was approximately 19% at the first peak and 49% at the second peak. Both hip and ground reaction forces remained consistent when the data for the group were fit using a simple linear regression. However, 5 individuals showed changes in maximum GRF across trials. Average loading rates were 163 kN/s or greater than 470 BW/s at the first force peak. Time to peak force for the first peak occurred at 0.01 seconds whereas the second peak occurred at 0.04 seconds.

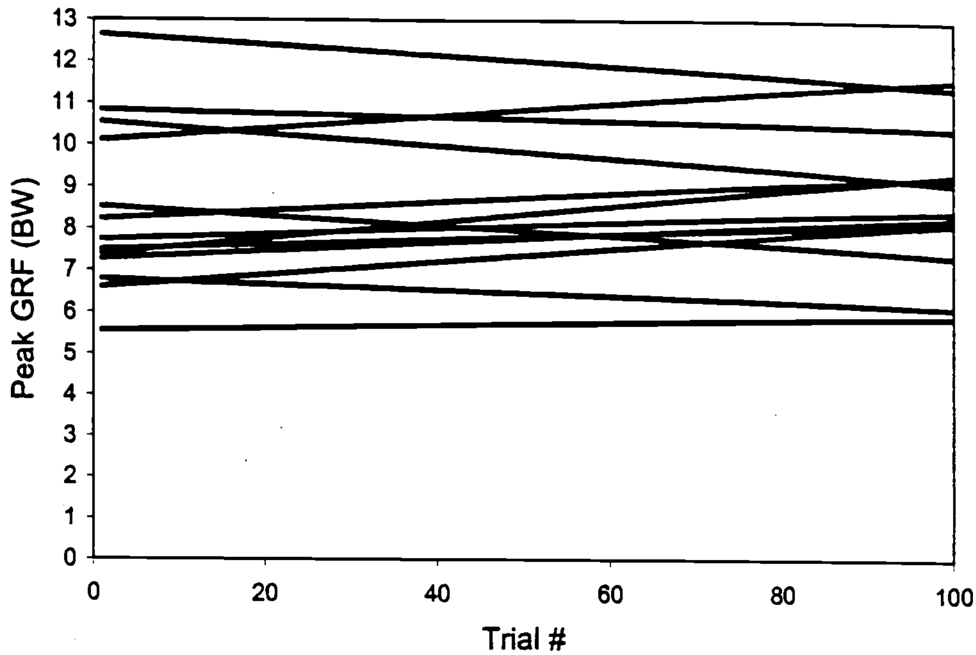

Figure 4 — Ground reaction force trend lines.

This study has several strengths. To our knowledge this is the first time average loading rates in children from a specific exercise associated with osteogenesis have been reported. Loading rate is thought to be important for bone, yet has not been previously determined for activities that result in bone mass accretion. Second, hip joint reaction forces were estimated from kinematic and kinetic data. To date, exercise interventions aimed at increasing bone mass at the hip only report ground reaction forces, where the load to the hip cannot be appropriately evaluated. Also, we calculated GRF data on 100 trials of drop landings. This represents the complete set of repetitions typical in an exercise session. Other studies that have reported force data collected only a few trials, and it can be argued that the few trials collected may not be representative of the complete load exposure. Another strength of this study is that both kinematic and force data were collected at fast sampling rates. This ensured that the highest frequency content of the forces and marker movements were recorded well above the nyquist frequency. Finally, all of our subjects had previously been in the experimental protocol that resulted in increased bone mass at the hip.

Some limitations in the study reduced our ability to provide a complete analysis of the drop landing activity in children. First, the children had not performed the drop landing for 6 months prior to participating in this study. By detraining for 6 months, normal growth could have caused coordination changes from the original exercise intervention. However, since the children progressed easily through the 100 trials, we believe that the forces collected after detraining accurately reflect those during training. In addition, since bone mass measurements and kinematic measurements were made on the left leg, it would have been best to assess only the forces applied to the left leg. However, it was felt that the children would not jump naturally if they were required to target half of the force plate. An additional limitation to this study is that the nature of the video recording system allowed for collection of very few trials. The small number of trials, combined with the use of only 13 subjects, might prevent possible changes in hip joint reaction forces across trials from being seen. Finally, our hip force estimates do not include muscle force estimation. Estimating muscle forces in the lower extremity would most likely increase the total force at the hip.

Comparing our results to those from other studies is difficult, as few exercise interventions have examined a bone response in children (Bradney et al., 1998; McKay et al., 2000; Morris et al., 1997). Of these, none have reported the effects of one specific activity and the associated force characteristics on bone mass in children. McKay et al. (2000) reported 1.2% higher hip bone mineral density in children after 8 months of participation in a program that incorporated jumping, hopping, and skipping in physical education classes. This group measured ground reaction forces from the various jumps in a small sample of children and found them to be 3 to 5 BW. McKay et al. did not report hip joint reaction forces or average loading rates. Thus, although they report a bone response, the force characteristics associated with the entire exercise session are not clear. By contrast, we have shown that ground reaction forces of approximately 8.5 times body weight resulted in a hip bone response in children that was over 5% greater than controls. Assuming equal forces on both feet, forces from drop landings were just above 4 times body weight at the ground for each leg, a value double that reported by McKay and colleagues. Thus, the higher magnitude forces that we report were associated with a greater skeletal response at the hip.

To date, exercise intervention studies for increasing bone mass have reported only ground reaction forces, but not hip joint reaction forces. However, it is the force at the hip that alters bone mass at the hip. An estimate of hip joint reaction forces provides a variable that should be more directly related to the resultant bone response. We report hip joint reaction forces at the first peak to be 4.7 times body weight. Since ground reaction forces at this peak were 5.8 BW, the first force peak is attenuated 19% at the hip. The short duration (0.01 s) over which the force was delivered is a consequence of the leg acting as a stiff spring. It should be noted that we calculated hip joint forces using a simple rigid body model. The rigid body approach represents a conservative estimate of joint reaction forces compared to other methods such as the wobbling mass model (Gruber, Ruder, Denoth, & Schneider, 1998). We believe our estimates of forces at the hip would be more accurate if contributions of muscular contraction were included, hence providing joint reaction forces along with joint forces.

Our reported average loading rates from 61-cm drop landings in children are considerably higher than those in pre- and postmenopausal women performing two-footed jumps from a height of 8.5 cm (Bassey, Rothwell, Littlewood, & Pye, 1998). Average loading rates in our study were 163 kN/s in children vs. 25.6 and 98.7 kN/s in pre- and postmenopausal women, respectively. Thus, a single leg was exposed to an average loading rate that was 1.5 to 6 times the rate reported in women landing from a height of 8.5 cm. Bassey et al. observed a response of 2.8% at the hip in premenopausal women and no change in postmenopausal women. However, we are cautious in comparing our results to those of Bassey and colleagues, since the young growing skeleton may be more responsive to lower loading rates than the adult skeleton, and because of the different drop heights in the interventions. Future studies in children are indicated to evaluate a bone response at lower loading rates.

The relative importance of loading cycles versus magnitude of loading is poorly understood in humans. However, investigations on this topic in animals has produced mixed results. Rubin and Lanyon (1987) reported no differences in osteogenic activity between turkey ulnas subjected to 0.5-Hz load reversals 36 times a day compared with 1,800 times a day, illustrating that magnitude of loading appears to be more important for osteogenesis compared to loading cycles. In contrast, Qin and Rubin (1998) reported that a low 9N load magnitude applied at 30 Hz for 60 minutes a day was enough to increase bone mass in the turkey ulna.

Children in the current study landed toe–heel, producing two high-magnitude force peaks (Figure 1a). This translates to 200 high-magnitude loads per exercise session. Interestingly, the correlation between average maximum ground reaction force and BMC percent change in our study was not significant ($r = 0.31$, $r^2 = 0.10$). While the low correlation may be due mostly to the low sample size, one cannot dismiss that the repetitions, not the magnitude, may be the variable responsible for the osteogenic effects. Whether or not fewer cycles at the same magnitude would provide a similar bone response is unclear and warrants further investigation.

Our data in children demonstrate that up to 81% of the ground reaction force from drop landing is delivered to the hip. Given the skeletal response from the drop landing protocol and our analysis of the associated force magnitudes and average loading rates, we now have a data point on the response surface to relate bone mass increases in children for future study of various combinations of force, rate, and number of load repetitions. These findings thus serve as a point of departure for further experiments designed to elucidate the shape of the response surface, and thus the relative importance of these variables in altering bone mass.

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Clinical Investigations

Bone Gains and Losses Follow Seasonal Training and Detraining in Gymnasts

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Abstract. The response of the human skeleton to high magnitude loading and unloading is poorly understood. Our aim was to evaluate changes in bone mineral density (BMD) in a group of intercollegiate gymnasts (n = 8, age = 18.6 ± 0.8 years) over 24 months that included two 8-month competitive seasons and two 4-month offseasons. BMD of the hip, spine, and whole body was evaluated by DXA (Hologic QDR-1000/W) at baseline, 8, 12, 20, and 24 months. Results indicated significant seasonal trends in BMD of the femoral neck, trochanter, total hip, lumbar spine, and whole body. Specifically, there was a strikingly consistent pattern of bone density increases over the training seasons followed by clear declines in the offseasons. Increases at the spine were 3.5% and 3.7% followed by declines of 1.5% and 1.3% in the offseasons. Total hip BMD increased 2.3% and 1.9% during the competitive seasons followed by decreases of 1.5% and 1.2% in the offseasons. We observed a significant 24-month increase of 4.3% in spine BMD but no significant overall change at the hip. In conclusion, the human skeleton demonstrated a measurable response to high magnitude loading and unloading that was consistent across bone sites over 24 months of observation.

Key words: Exercise — Mechanical loading — Osteoporosis — BMD — Peak bone mass

Mechanical loading from exercise is known to increase bone mineral density (BMD) in young women [1–3]. Specifically, gymnastics training, where forces are applied at high load magnitudes, leads to higher BMD than activities with lower load magnitudes such as running and swimming [1]. We have reported that gymnasts have BMD values at the spine and hip that are 30–35% higher than runners, despite a similar prevalence of menstrual irregularities [4]. Furthermore, we have shown that gymnasts have bone gains over their competitive training season, despite higher initial bone values and menstrual cycle irregularities [5]. However, the effect of training and detraining on the skeleton over an extended period of time has not been reported in elite gymnasts. Although there is evidence that withdrawal of training in the adult skeleton results in a reversal of bone gains [6, 7], the seasonal skeletal response to high magnitude training and detraining over an extended period of time in athletes is poorly understood.

Thus, we asked the following research question: Does bone mineral density in elite female gymnasts have a seasonal pattern whereby BMD declines in the offseason then increases in the competitive season? We hypothesized that systemic changes in bone would follow seasonal patterns of training and detraining. Additionally, since there are reports of bone increases through the third decade at the spine [8, 9], we also asked: Does gymnastics training during the young adult years result in a net bone gain in spite of seasonal declines? To answer these questions, we conducted a within-subjects study to evaluate changes in BMD of intercollegiate gymnasts over 2 years that included two 8-month competitive training periods (September–May) and two 4-month offseason detraining periods (May–September).

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Methods

Subjects and Measurements

Nine female athletes (18.8 ± 0.9 years) were recruited from the Oregon State University NCAA Division I gymnastics team and agreed to participate in the study over 2 years (Table 1). Each athlete completed a health history at the beginning of each training season. Of the nine gymnasts, six were eumenorrheic (10–12 menstrual cycles/year prior to and over the 2-year study period), two were oligomenorrheic (3–4 menstrual cycles during the offseasons of the study period), and one was amenorrheic (no menstrual cycles over the study period). Bone mineral density of the lumbar spine, right proximal femur, and whole body was assessed by DXA (Hologic QDR-1000/W, Waltham, MA) at baseline, 8 months, 12 months, 20 months, and 24 months. Body composition was derived from whole body scans. In-house coefficients of variation for BMD are 1–2% and 1.5% for tissue composition. During the competitive season, gymnasts trained 5 days per week, 4 hours/day. By contrast, in the offseason, the athletes did not engage in organized gymnastics training. Other activities in which they participated during the offseasons included aerobics, weightlifting, and running but these did not account for more than 3 hours per

Table 1. Baseline characteristics of 9 intercollegiate competitive gymnasts (mean ± SD)

Age (yrs.)	18.8 ± 0.9
Height (cm)	154.9 ± 2.8
Weight (kg)	53.6 ± 5.3
Onset of training (yrs.)	11.3 ± 3.2
Age menarche (yrs.)	15.9 ± 1.5
Menstrual status (n)	
Eumenorrhea	6
Oligomenorrhea	2
Amenorrhea	1

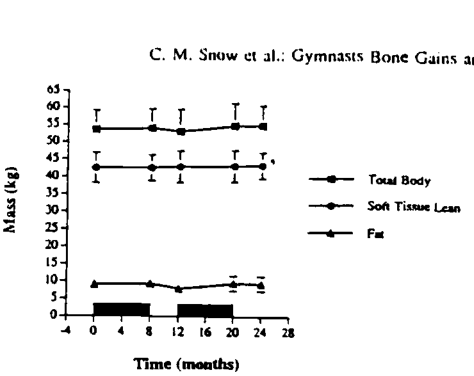

Fig. 1. Changes in total body weight and lean and fat mass over 24 months in eight intercollegiate gymnasts. The asterisk (*) represents a significant linear trend for a 24-month increase in soft tissue lean mass ($P = 0.023$). Black bars indicate the timing of the competitive training seasons. Data are expressed as mean ± SD.

week. This study was approved by the Oregon State University Institutional Review Board and all subjects gave written informed consent.

Statistics

Changes in selected body composition and bone mineral variables over five separate measurement sessions (months 0, 8, 12, 20, and 24) were analyzed with a repeated measures analysis of variance (ANOVA). The time between months 0–8 and 12–20 were the two consecutive 8-month competitive training seasons, whereas the time between months 8–12 and 20–24 were the two consecutive 4-month "off" seasons for the gymnasts. To detect the presence of significant time-related trends across the five separate measurement sessions, we partitioned the repeated measures ANOVA into four orthogonal polynomial trends (linear, quadratic, cubic, and quartic). A positive linear trend would be consistent with the interpretation of a 24-month increase. By contrast, a positive quartic trend would be consistent with the interpretation of temporary gain or increase during the 8-month competitive training seasons followed by a reversal or decrease during the subsequent 4-month "off-seasons". To determine whether a linear trend in bone was associated with a linear trend in soft tissue lean mass, Pearson correlations were used. Thus, the 24-month changes in site-specific BMD were predicted from the 24-month changes in soft tissue lean mass.

The main statistical advantage of a repeated measures design over a completely randomized design is that it usually yields a smaller error term, thereby facilitating the detection of significant trends. However, the main limitation of a repeated measures design is when the ***compound symmetry assumption*** is violated by the presence of either unequal variances or unequal correlations among the repeated measurements [10]. Thus, we tested the assumptions of our study design by examining F maximum tests for homogeneity of variances and intercorrelation matrices for each dependent variable set of five repeated measurements. Results are expressed as mean ± 1 SEM unless otherwise indicated. Significant trends were defined by a value of $P < 0.05$.

Because of potential differences in skeletal responses due to reproductive hormone status, we evaluated the individual data of the three athletes with menstrual cycle irregularities (one amenorrheic subject and two oligomenorrheic subjects). Compared with eumenorrheic gymnasts, we observed different patterns of response in the one amenorrheic gymnast (in *linear,* but not seasonal quartic trends), but no differences in response patterns in the oligomenorrheic gymnasts. Thus, we did not include the amenorrheic athlete in the statistical analyses.

Results

In testing the *compound symmetry assumption* of the study design, equal variances were assured by the finding of nonsignificant F maximum ratios between the highest and lowest variance of each dependent variable set of five repeated measurements ($P \geq 0.08$). Each dependent variable set of repeated measurements met the assumption of equal correlations, as the intercorrelations ranged from $r = 0.85$ ($P = 0.008$) to $r = 0.99$ ($P < 0.001$). Thus, the analyses of seasonal trends in the body composition and bone mineral variables reported herein were statistically robust.

There was a significant linear trend for an increase in lean mass ($P = 0.023$), as we observed a 2.6% increase in this variable over 24 months (Fig. 1, Tables 2, 3). By contrast, no significant time-related or seasonally related trends were detected for total body weight ($P \geq 0.050$) or fat mass ($P = 0.269$). However, the 3.0% increase in mean total body weight over 24 months had a linear trend of borderline significance ($P = 0.05$). The linear trend in soft tissue lean mass was more consistent than the linear trend in total body weight.

There were significant and independent linear ($P = 0.006$) and quartic ($P = 0.031$) trends for changes in whole body BMD (Fig. 2). Thus, the seasonal quartic trend is due to the 1.2% and 1.6% increases in mean whole body BMD during the 8-month competitive training seasons that were followed by 0.3 and 0.4% decreases in mean whole body BMD during the subsequent 4-month offseasons. Because the competitive seasonal increases (+2.8%) exceeded the off-seasonal decreases (–0.7%) in mean whole body BMD, there was a net 24-month linear change in whole body BMD of +2.1%. The 24-month change in whole body BMD was not correlated with the 24-month change in soft tissue lean mass ($r = 0.46$, $P = 0.250$). However, the magnitude of the correlation suggests that 21% of the linear increase in whole body BMD was accounted for by the linear increase in soft tissue lean mass.

Somewhat similar to whole body BMD, there were significant and independent linear ($P = 0.031$) and quartic ($P = 0.004$) trends for changes in lumbar spine BMD (Fig. 3). Thus, the strong seasonal quartic trend is due to the finding of 3.5 and 3.7% increases in mean lumbar spine BMD during the 8-month competitive training seasons that were followed by 1.5% and 1.3% reductions in mean lumbar spine BMD during the subsequent 4-month offseasons (Tables 2 and 3). Because the competitive seasonal increases (+7.2%) exceeded the off-seasonal decreases (–2.8%) in mean lum-

Table 2. Anthropometric and BMD values (mean ± SD) in eumenorrheic and oligomenorrheic gymnasts (n = 8). Baseline is the beginning of the first competitive season, 8 months the end of the first competetive season, 12 months the end of the first summer offseason, 20 months the end of second competitive season, and 24 months the end of the second summer offseason

	Baseline	8 months	12 months	20 months	24 months
Anthropometry					
Body weight (kg)	53.8 ± 5.6	54.6 ± 5.7	53.7 ± 6.4	55.5 ± 6.6	55.4 ± 5.9
Fat mass (kg)	8.9 ± 1.3	9.3 ± 1.9	9.4 ± 1.7	9.5 ± 2.1	9.4 ± 2.1
Lean mass (kg)	42.7 ± 4.4	43.1 ± 3.8	43.5 ± 4.6	43.7 ± 4.7	43.8 ± 3.8
Body fat (%)	16.6 ± 1.4	16.9 ± 2.0	17.0 ± 1.5	17.1 ± 2.6	16.9 ± 2.3
BMD (g/cm^2)					
Whole body	1.104 ± 0.06	1.117 ± 0.06	1.114 ± 0.06	1.132 ± 0.06	1.127 ± 0.06
Lumbar spine	1.141 ± 0.1	1.181 ± 0.1	1.163 ± 0.1	1.206 ± 0.1	1.190 ± 0.1
Femoral neck	1.091 ± 0.1	1.113 ± 0.1	1.096 ± 0.1	1.121 ± 0.07	1.098 ± 0.08
Trochanter	0.908 ± 0.08	0.926 ± 0.09	0.900 ± 0.08	0.917 ± 0.06	0.915 ± 0.08
Total hip	1.136 ± 0.08	1.162 ± 0.08	1.144 ± 0.09	1.166 ± 0.07	1.152 ± 0.08

Table 3. Percent changes in anthropometric and BMD variables by season and overall in competitive eumenorrheic/oligomenorrheic gymnasts (n = 8). Categories are as follows: Season 1 is the % change over the first competitive training season (0-8 months), offseason 1 is the % change over the first summer of detraining (8-12 months), season 2 is the % change over the second competitive training season (12-20 months), off season 2 is the % change over the second summer of detraining (20-24 months), and overall is the % change from 0-24 months

	Season 1	Off season 1	Season 2	Off season 2	Overall
Anthropometry					
Body weight	1.5 ± 2.4	−1.5 ± 7.0	3.7 ± 9.8	−0.1 ± 1.9	3.0 ± 6.0
Fat mass	4.5 ± 15.7	1.1 ± 5.5	1.1 ± 11.6	1.1 ± 2.1	5.6 ± 13.8
Lean mass	0.9 ± 2.1	0.9 ± 3.4	0.5 ± 2.6	0.7 ± 2.8	2.6 ± 2.4
Bone mineral density					
Whole body	1.2 ± 0.9	−0.3 ± 0.9	1.6 ± 1.5	−0.4 ± 1.3	2.1 ± 1.4
Lumbar spine	3.5 ± 2.8	−1.5 ± 1.9	3.7 ± 3.0	−1.3 ± 2.5	4.3 ± 4.2
Femoral neck	2.0 ± 2.9	−1.5 ± 2.0	2.3 ± 4.9	−2.1 ± 3.6	0.6 ± 4.7
Trochanter	2.0 ± 3.1	−2.8 ± 2.8	1.9 ± 3.8	−0.2 ± 2.1	0.9 ± 3.5
Total hip	2.3 ± 1.8	−1.55 ± 1.7	1.9 ± 2.6	−1.2 ± 1.8	1.4 ± 2.3

bar spine BMD, there was a net 24-month linear change in mean lumbar spine BMD of +4.3%. The 24-month change in lumbar spine BMD was *not* correlated with the 24-month change in soft tissue lean mass (r = 0.11, P = 0.790), which suggests that the linear increase in lumbar spine BMD was largely independent of the linear increase in soft tissue lean mass.

Similar to the whole body and spine, there were significant quartic seasonal trends (P = 0.031) in femoral neck and trochanter BMD. However, by contrast to the whole body and lumbar spine, we observed no significant linear trends (P = 0.639) in BMD at these regions of the hip (Fig. 4). The seasonal quartic trend at the femoral neck is due to the 2.0% and 2.3% increases in mean femoral neck BMD during the 8-month competitive training seasons that were followed by 1.6%–2.0% decreases in mean femoral neck BMD during the subsequent 4-month "off-seasons" (Tables 2 and 3). Because the competitive seasonal increases were largely balanced by the off-season decreases in mean femoral neck BMD, the net 24-month linear change in femoral neck BMD of +0.8% was not statistically detectable (P =

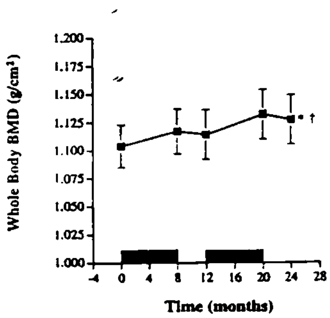

Fig. 2. Changes in whole body bone mineral density over 24 months in intercollegiate gymnasts. The asterisk (*) represents a significant linear trend for a 24-month increase in whole body BMD (P = 0.006) in the group of eight gymnasts. The dagger (†) represents a significant quartic seasonal trend in this group for repeated increases and decreases in whole body BMD (P = 0.031). Black bars indicate the timing of the competitive training seasons. Data are expressed as mean ± SEM.

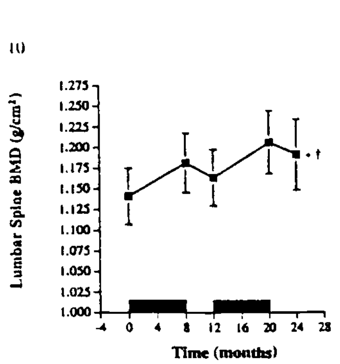

Fig. 3. Changes in lumbar spine BMD over 24 months in intercollegiate gymnasts. The asterisk (*) represents a significant linear trend for a 24-month increase in lumbar spine BMD (P = 0.031) in the group of eight gymnasts. The dagger (†) represents a significant quartic seasonal trend for repeated increases and decreases in lumbar spine bone mineral density (P = 0.004). Black bars indicate the timing of the competitive training seasons. Data are expressed as mean ± SEM.

0.639). The seasonal quartic trend at the femoral trochanter is due to the 2.0% and 1.9% increases in BMD during the 8-month competitive training seasons that were followed by 2.8% and 0.2% decreases in BMD during the subsequent 4-month off-seasons (Tables 2 and 3). Because the competitive season increases were largely balanced by the off-season decreases in mean trochanteric BMD, the net 24-month linear change in femoral trochanter BMD of +0.9% was not statistically detectable (P = 0.849). The same patterns were observed at the total hip as there was a significant quartic seasonal trend (P = 0.013) for the eight gymnasts, but no significant linear trend (P = 0.08) in BMD (Tables 2 and 3).

We observed only one effect size above the conventional threshold of 0.20 for a "small" effect [13] among all of the nonsignificant linear and quartic seasonal trends for the changes in body composition and BMD reported herein (Table 4). The nonsignificant linear trend for the 24-month change in total body mass should be cautiously interpreted because the effect size was 0.44 and the statistical power was only 53%. Due to the limited sample size of only eight gymnasts, the present study is insufficiently powered to detect the small-to-medium 24-month linear change in total body mass. By contrast, the other nonsignificant trends were observed with such negligible effect sizes, ranging from 0.001 to 0.171, that expansions in sample size would be of limited value.

Discussion

In this within subjects design, we evaluated the skeletal response of intercollegiate gymnasts to high magnitude loading and unloading over 24 months. We also examined the overall changes in BMD over the 2 years of observation. We observed a distinct pattern of use and disuse during the competitive and off-seasons, respectively. In the initial 12-month period, BMD increased in spine, hip, and whole body during the 8-month training season and declined in the subsequent 4 offseason months. The same pattern of gain and loss occurred during the second 12 months of observation. Over the 24-month period, we observed net gains in both spine and whole body BMD, but no net changes at the hip in these elite female athletes.

Strengths of this study include the longitudinal assessment of athletes and the homogeneity of the study population with respect to physical activity. To our knowledge, we are the first to report the bone response to training and detraining over multiple competitive seasons in athletes. Because we observed these athletes for 2 full years, we were able to detect not only linear, but also quadratic, cubic, and quartic trends in the data. This eliminated anomalies that could have existed with a shorter observation time. Furthermore, the homogeneity in our group ensured, as closely as possible, that all subjects received similar training during the competitive season. Activity was less standardized during the offseason and no gymnasts had structured practice during these 4 months.

This study has several limitations. We did not have a control group, thus it is not possible to determine whether the significant linear trends in spine and whole body BMD were related to gymnastics training or simply continued bone accrual during the third decade at these sites. We also cannot be certain that the declines in BMD during the summer were not spurious without a control group for comparison. Although vitamin D status is reportedly lower with reduced exposure to sunlight [14–16], to our knowledge, only one study has reported that BMD has seasonal variations [16]. Given the significant quartic trends and the fact that the summer decreases are opposite of what would be expected based on seasonal vitamin D status, our data likely reflect true patterns of bone gain and loss. In addition, we did not evaluate reproductive endocrine status in our subjects, thus we could not assess the bone response to potentially changing hormones, particularly in the athletes with menstrual irregularities. However, it would be more common to observe that estrogen levels would decline over training seasons and increase in the off season and this would be directly opposite of the bone responses that we observed. In addition, since we did not examine calcium intake prospectively, we cannot evaluate the role of calcium on linear changes in bone. Lastly, our sample size was small. Future work is needed to definitively replicate or refute our findings in a group of 20 or more athletes.

The few reports of the bone response to detraining in the adult skeleton corroborate a disuse phenomenon. Dalsky et al. [6] reported that spine mineral content increased in postmenopausal women after 9 months of exercise then returned to baseline after 13 months of detraining. Our recent work in mature adult premenopausal women demonstrates that 12 months of impact and resistance training produced gains in hip BMD in mature premenopausal women that were followed by a reversal in bone gains over a 6-month detraining period [11]. The extent to which the bone values in gym-

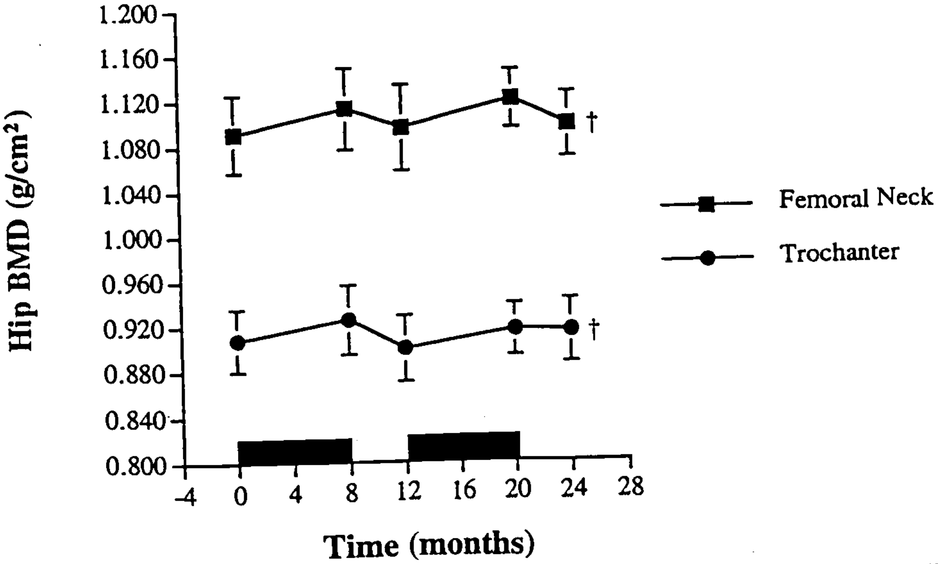

Fig. 4. Changes in hip BMD over 24 months in intercollegiate gymnasts. The dagger (†) represents a significant quartic seasonal trend for repeated increases and decreases in hip BMD at the femoral neck ($P = 0.028$) and trochanter ($P = 0.031$) in the group of eight gymnasts. Black bars indicate the timing of the competitive training seasons. Data are expressed as mean ± SEM.

Table 4. Effect sizes and statistical power (%) for all nonsignificant (NS) findings. By contrast to the effect size of the nonsignificant linear trend in total body mass, the other nonsignificant trends were observed with effect sizes ranging from 0.001 to 0.171. Because these sizes are so close to zero and well below the threshold of a "small" effect size, the observed effects are of such a negligible magnitude that an expanded sample size would be of little value

Variable	NS Trend	Effect Size	Power
Total body mass	Linear	0.443	53
	Quartic	0.120	14
Soft tissue lean mass	Quartic	0.001	5
Fat mass	Linear	0.171	18
	Quartic	0.005	5
Femoral neck BMD	Linear	0.033	7
Trochanter BMD	Linear	0.006	5

nasts would decline without resumption of training is not known, but it is expected that a new mechanical usage setpoint would be established to accommodate reduced mechanical loading patterns. However, we anticipate that BMD would remain higher than average given their early age of training (11 years) and bone values at the hip and spine that ranged between 20% and 50% above the age-adjusted mean. Khan et al. [12] reported higher hip BMD in 51-year-old retired female ballet dancers (compared with normal control women) who had undertaken ballet at age 10–12 years, an age similar to that of the gymnasts in our study.

Bone gain is reported to continue at the spine and whole body well into the third decade, but end early in the third decade at the hip [8, 9, 17]. Our data support these results. We observed net increases in BMD at the spine and whole body over 2 years that were not accompanied by increases at the femoral neck or trochanteric regions of the hip. These occurred despite initial bone values at the spine that were 10% higher than normal for women of similar age. In a 5-year longitudinal study of young women, Recker et al. [8] reported a median gain, expressed as a percentage per decade of 6.8% in spine BMD and 12.5% in whole body mineral content in young adult women. In that study, the age at which mineral acquisition ceased was 28–30 years. In a longitudinal evaluation of white females, Hui et al. [9] reported that lumbar spine bone growth continued until age 36 whereas femoral neck bone gain ended by 24 years of age. We observed a net gain of 4.3% in spine and 2.1% in whole body BMD over 2 years, from ages 19 to 21 years. However, bone density at the hip did not increase over this period. Because the present effect size for the 2-year change in hip BMD was so close to zero (≤0.03), our inability to detect significant mineral acquisition at the hip cannot be easily dismissed as a function of our small sample size. The increase we observed at the spine, if expressed per decade, is higher than that reported by Recker et al. [8]. However, Recker et al. found that both increased physical activity and calcium intake were associated with greater gains in bone in young adult women. Thus, it is possible that gymnastics training may enhance bone accrual at the spine in the early

20s. However, future work comparing competitive gymnasts to normally active young women will elucidate the role of high magnitude loading in producing bone gain in the second and third decades of life.

Lean mass is a strong predictor of BMD. We have previously shown it to be an independent predictor of spine and whole body BMD in adolescent girls and mature premenopausal women [11, 18]. Although the correlation between whole body BMD and lean mass that we report was not significant, it did explain 21% of the linear increase in whole body BMD. In a sample size of 20 or more gymnasts, this correlation would have been significant. The fact that the improvements in lean mass explained less than 2% of the linear increase, spine BMD indicates that changes at this bone site were not the result of the significant overall improvement in whole body lean mass, but more likely due to the high mechanical loads from gymnastics training.

Given our previous reports that gymnasts with menstrual cycle irregularities have higher bone density than runners and that regional bone density of gymnasts increases over the competitive training season, we did not expect to observe a different response to training and detraining in those athletes with menstrual cycle disturbances compared with those who were eumenorrheic [4, 5]. As expected, all gymnasts, regardless of menstrual status, exhibited a seasonal quartic skeletal response to training and detraining at the hip and the spine. However, since the one amenorrheic gymnast did not exhibit a *linear* trend at the whole body or spine, her data were not included in the analyses. Future studies should examine amenorrheic athletes to more fully evaluate the effect of long-term effects of hypoestrogenemia on bone mineral accrual in the early adult years.

Although the gymnasts engaged in aerobic and weight-training activities in the off-seasons, the magnitude and volume of training were clearly not sufficient to offset the marked reductions in high impact loading from gymnastics. Ground reaction forces from running average 2–4 times body weight and forces at the spine from high intensity weight lifting are 5–7 times body weight [19]. By contrast, vertical forces at the ground are 10–18 times body weight from gymnastics landings [20]. Furthermore, the time spent training during the competitive season averaged more than 20 hours per week, markedly greater than only 3 hours per week of structured exercise and no gymnastics training in the offseason.

In summary, the skeleton responds to changing patterns of extreme mechanical loading. Since stimulus withdrawal leads to reductions in bone density, activity must be continued in order to maintain BMD. Furthermore, in our small sample, BMD at the whole body and spine, but not hip, continue to increase late in the second and early third decade in young women and increasing mechanical loads may enhance this response in young adult women.

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APPENDIX B

INFORMED CONSENT FORMS, PHYSICAL ACTIVITY QUESTIONNAIRE, GENERAL HEALTH HISTORY QUESTIONNAIRE, HARVARD MEDICAL SCHOOL YOUTH FOOD SURVEY, AND TANNER STAGE CRITERIA

APPENDIX B. 1

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
INFORMED CONSENT FORM FOR JUMPING GROUP

INTRODUCTION and STUDY DETAILS
My child has been invited by Dr. Christine Snow (Principal Investigator) and Robyn Fuchs (Student Investigator) to participate in this study looking at how jumping exercises effect bone growth in children. In this exercise study we will be exploring the effect of a regular physical education program with added jumping exercises on improving bone mass in young children, in addition to how bone responds when the jumping exercises are discontinued.

PROGRAM DETAILS
I am aware that this study will take place over a 14-month period. An explanation of the exercise program and the testing measurements that will be used are explained below.

MEASUREMENTS
It has been explained to me that as the parent I will be asked to bring my child in for testing to the Oregon State University Bone Research Laboratory in October (1998), May (1999), and November (1999). The approximate time that it will take to complete all tests will be one hour and include the following:

Bone Mineral Density Testing: It has been explained to me that the bone mineral density test is non-invasive and will not hurt my child. This test will require my child to lie still on an x-ray table for approximately 6 minutes for a bone scan of the hip (1 minute) and spine (2 minutes). The radiation dose is considered safe to administer and has been used in many studies. The amount of radiation that my child will receive is less than that from natural background radiation during a plane trip across the country, or from a day outside in the sun. Additional information regarding the bone mineral density tests was presented to me by the principal investigator, pediatrician and radiologist at the special informational meeting.

Body Composition Testing: It has been explained to me that my child will have his/her body composition measured using skinfold calipers. My child and I have been shown how the calipers work, and it has been explained to me that this procedure will not hurt my child. Measurements will only be taken on the arm and shoulder. The way in which my child's body composition will be measured has been used in other children of this age group and has been demonstrated as a safe and reliable way to measure body fat.

Physical Activity Questionnaire: It has been explained to me that I will help my child complete a questionnaire that will ask questions about the types of activities my son/daughter participates in on a regular basis.

Food Survey: It has been explained to me that I will help my child record his/her food intake using a food survey designed specifically for children and adolescents. This survey will take approximately 20 minutes to complete. This survey will require me to answer questions based on the types of foods my son/daughter consumes on an annual basis.

EXERCISE INTERVENTION DETAILS

Training: It has been explained to me that if my child is in the exercise program he/she will perform jumping exercises that will take approximately 10-15 minutes to complete. The jumping exercises will take place from October (1998) to May (1999), three times per week at a regularly scheduled time. All exercise classes will be led by a qualified instructor from this research project. Alternative activities will be provided if my child is unable to participate in the jumping exercises.

Detraining: It has been explained to me that my child will be asked to come back in for testing in November (1999), 7-months after the conclusion of the jumping class. During this 7-month time period my child will not participate in jumping exercises at the elementary school, and will be asked not to perform these exercises at home.

BENEFITS & RISK OF INJURY

My child will receive valuable information regarding his/her bone mineral density, body composition, and nutrition (i.e. total calories, calcium, vitamin C, vitamin D) following the completion of the exercise program. Information obtained from this study will help in providing rationale for the economic support of physical education in public schools as a preventive strategy for osteoporosis. It has been explained to me that the possibility of injury from exercise may occur; however, the risk for injury is minimal. It is important to note that no major injuries were reported from a pilot study of young children performed in our laboratory. I understand that the University 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

It has been explained to me that confidentiality will be maintained for my child by a number coding system and that only the researchers will have knowledge of my child's name. I have been informed that the results of this study may be published in scientific literature, and that these data will not reveal the identity of my child.

INVESTIGATOR INFORMATION

I have been informed and understand that nature and purpose of this research study. The researchers have offered to answer any questions that I may have. I understand that my child's participation in this study is voluntary and that I may remove my child from the study at any time without sacrificing of benefits to which my child is entitled. Questions about the research or any aspect of my child's participation should be directed to Dr. Christine Snow at 737-6788 or Robyn Fuchs at 737-5935. I have read the above information and agree for my child to participate.

Subject Signature________________________________Date________________

Parent/Guardian Signature_________________________Date________________

Investigators Signature____________________________Date________________

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
INFORMED CONSENT FORM FOR CONTROL GROUP

INTRODUCTION and STUDY DETAILS

My child has been invited by Dr. Christine Snow (Principal Investigator) and Robyn Fuchs (Student Investigator) to participate in this study looking at how jumping exercises effect bone growth in children. In this exercise study we will be exploring the effect of regular physical education program on improving bone mass in young children, in addition to how bone responds when the jumping exercises are discontinued.

PROGRAM DETAILS

I am aware that this study will take place over a 14-month period. An explanation of the exercise program and the testing measurements that will be used are explained below.

MEASUREMENTS

It has been explained to me that as the parent I will be asked to bring my child in for testing to the Oregon State University Bone Research Laboratory in October (1998), May (1999), and November (1999). The approximate time that it will take to complete all tests will be one hour and include the following:

Bone Mineral Density Testing: It has been explained to me that the bone mineral density test is non-invasive and will not hurt my child. This test will require my child to lie still on an x-ray table for approximately 6 minutes for a bone scan of the hip (1 minute) and spine (2 minutes). The radiation dose is considered safe to administer and has been used in many studies. The amount of radiation that my child will receive is less than that from natural background radiation during a plane trip across the country, or from a day outside in the sun. Additional information regarding the bone mineral density tests was presented to me by the principal investigator, pediatrician and radiologist at the special informational meeting.

Body Composition Testing: It has been explained to me that my child will have his/her body composition measured using skinfold calipers. My child and I have been shown how the calipers work, and it has been explained to me that this procedure will not hurt my child. Measurements will only be taken on the arm and shoulder. The way in which my child's body composition will be measured has been used in other children of this age group and has been demonstrated as a safe and reliable way to measure body fat.

Physical Activity Questionnaire: It has been explained to me that I will help my child complete a questionnaire that will ask questions about the types of activities my son/daughter participates in on a regular basis.

Food Survey: It has been explained to me that I will help my child record his/her food intake using a food survey designed specifically for children and adolescents. This survey will take approximately 20 minutes to complete. This survey will require me to answer questions based on the types of foods my son/daughter consumes on an annual basis.

EXERCISE INTERVENTION DETAILS

Training: It has been explained to me that if my child is in the exercise program he/she will perform stretching exercises that will take approximately 10-15 minutes to complete. The exercise program will take place from October (1998) to May (1999), three times per week at a regularly scheduled time. All exercise classes will be led by a qualified instructor from this research project. Alternative activities will be provided if my child is unable to participate in the stretching exercises.

Detraining: It has been explained to me that my child will be asked to come back in for testing in November (1999), 7-months after the conclusion of the exercise program. During this 7-month time period my child will not participate in the jumping exercises at the elementary school, and will be asked not to perform these exercises at home.

BENEFITS & RISK OF INJURY

My child will receive valuable information regarding his/her bone mineral density, body composition. and nutrition (i.e. total calories, calcium, vitamin C, vitamin D) following the completion of the exercise program. Information obtained from this study will help in providing rationale for the economic support of physical education in public schools as a preventive strategy for osteoporosis. It has been explained to me that the possibility of injury from exercise may occur; however, the risk for injury is minimal. It is important to note that no major injuries were reported from past exercise intervention studies of young children performed in our laboratory. I understand that the University 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

It has been explained to me that confidentiality will be maintained for my child by a number coding system and that only the researchers will have knowledge of my child's name. I have been informed that the results of this study may be published in scientific literature, and that these data will not reveal the identity of my child.

INVESTIGATOR INFORMATION

I have been informed and understand that nature and purpose of this research study. The researchers have offered to answer any questions that I may have. I understand that my child's participation in this study is voluntary and that I may remove my child from the study at any time without sacrificing of benefits to which my child is entitled. Questions about the research or any aspect of my child's participation should be directed to Dr. Christine Snow at 737-6788 or Robyn Fuchs at 737-5935. I have read the above information and agree for my child to participate.

Subject Signature__________________________________Date_______________

Parent/Guardian Signature__________________________Date_______________

Investigators Signature______________________________Date_______________

APPENDIX B.2

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
PHYSICAL ACTIVITY QUESTIONNAIRE

Child's Name:________________________________ **Date:**______________

1. Do you walk to school (yes / no)? If so how long does it take to walk to and from school (minutes)?
2. What activities do you normally do at recess (ex. run, tag, bars)?
3. Television watched (# hours after school/evening)?
   School Nights: ____________ Non School Nights:__________
4. Computer/video games (# hours after school/evening)?
   School Nights: ____________ Non School Nights:__________
5. Study or do homework (# hours after school/evening)?
   School Nights: ____________ Non School Nights:__________
6. Sleep (hours per night)?
   School Nights: ____________ Non School Nights:__________
7. Time spent each week doing the following activities (minutes).
   Specify if the activity is season specific (i.e. swimming lessons
   3 times per week for 30 minutes during summer months).
   Cycling______________________________
   Swimming______________________________
   Running/Running games______________________
   Dance/Ballet______________________________
   Baseball______________________________
   Basketball______________________________
   Soccer______________________________
   Tennis______________________________
   Gymnastics______________________________
   Karate______________________________
   Football______________________________
   Hockey______________________________
   Horse Riding______________________________
   Weight Lifting______________________________
   Other______________________________
8. Do you participate in team sports (yes / no)?
9. Details for team sports participation

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

APPENDIX B.3

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
GENERAL HEALTH HISTORY QUESTIONNAIRE

________________________________ ________________
Child's last name First Middle Date of birth

________________________________ ________________
Address, Street Home phone

____
City, State

________________________________ ________________
Parent/Guardian's last name First Middle Home phone

________________________________ ________________
Address, Street Work phone

____
City, State

________________________________ ________________
Person to contact in case of emergency Home phone/ Work phone

****

______pounds ______ft_____inches
Child's Weight Child's Height Male Female (circle one)

*Height and Weight Measured at OSU

****

Race/ethnic background of your child (Please check as many as apply)

- Caucasian (white) ☐
- Asian (Oriental) ☐
- African (black) ☐
- Mexican, Hispanic, or Latino ☐
- American Indian ☐
- Pacific Islander ☐

If none of the above choices apply to you,
please use your own description.______________

____

PAST HISTORY (Check if yes)
Has your child ever had?

Diabetes	______
Heart murmur	______
Heart defect	______
Asthma	______
Epilepsy	______
Back injury	______
Serious illness	______
Operations	______
Other musculoskeletal injury or problems	______

FAMILY HISTORY (Check if yes)
Have you, or your other children had?

Diabetes	______
Heart attacks	______
High blood pressure	______
High cholesterol	______
Congenital heart disease	______
Heart operations	______

Other________________________________
____
____

PRESENT SYMPTOMS REVIEW (Check if yes)
Has your child recently had?

Chest pain	______
Shortness of breath	______
Heart palpitations	______
Cough on exertion	______
Coughing blood	______
Back pain	______
Painful, stiff or swollen joints	______

Other________________________________
____

MEDICAL/HEALTH AND PHYSICAL ACTIVITY QUESTIONS

1. Date of your child's last medical exam?
2. Please list your child's present medications and dosages here (include vitamins):
   Child's Physician:______________________
3. How would you rate you son/daughter's present level of health?
4. Does your child experienced any pain or shortness of breath with moderate exercise?
5. How physically fit do you feel your child is at the present time? (Circle one) poor / moderate / active / very active /

HEALTH HABITS

Consumption of calcium-rich daily products
How many 8 oz glasses of milk does your child drink per day?____per week?__
How many servings of cheese (1 oz) does your child eat per day?________per week?
How many servings of yogurt (1 cup) does your child eat per week?

Body Weight
What was your child's weight 1 month ago?
What was your child's weight 6 months ago?

Cola Beverages
How many cola beverages does your child drink daily?
How many years has your child been drinking cola beverages on a regular basis?

OSTEOPOROSIS RISK FACTORS

Please circle true or false for the following. If you think a statement may apply to your child but are not sure, place a question mark (?) by that statement.

1. true false My child has been treated with cortisone or similar drugs.
2. true false My child has a history of the blood tumor, leukemia.
3. true false My child has lactase deficiency (inability to digest milk).
4. true false My child takes anabolic steroids now or has in the past.
5. true false My child avoids milk and other dairy products.
6. true false My child usually eats meat at least twice a day.
7. true false On average, my child usually drinks 2 or more soft drinks daily.
8. true false My child is very physically active most of the time.
9. true false My child has been treated with chemotherapy for cancer.
10. true false My child has received an organ transplant
11. true false My child has had trouble with anorexia nervosa or bulimia.

______________________________ _______________

Parent/Guardian Signature Date

APPENDIX B.4

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY

HARVARD YOUTH FOOD SURVEY

MARKING INSTRUCTIONS

- Use a **NO. 2 PENCIL** only.
- Do not use ink or ballpoint pen.
- Darken in the circle completely.
- Erase cleanly any marks you wish to change.
- Do not make any stray marks on this form.

USE NO. 2 PENCIL ONLY

The RIGHT way to mark your answer! ●

The WRONG way to mark your answers!

1. What is your AGE?

- ○ Less than 9
- ○ 9
- ○ 10
- ○ 11
- ○ 12
- ○ 13
- ○ 14
- ○ 15
- ○ 16
- ○ 17
- ○ 18 or older

2. Are you:

- ○ Male
- ○ Female

3. Your Height

FEET | INCHES

4. Your Weight (lbs)

Questionnaire refers to what you ate over the past year.

5. Do you now take vitamins (like Flintstones, One-A-Day, etc.)?

○ No ○ Yes → **If yes)**

a) How many vitamin pills do you take a week?

- ○ 2 or less
- ○ 3 - 5
- ○ 6 - 9
- ○ 10 or more

b) For how many years have you been taking them?

- ○ 0 - 1 years
- ○ 2 - 4
- ○ 5 - 9
- ○ 10+ years

6. How many teaspoons of sugar do you ADD to your beverages or food each day?

- ○ None/less than 1 teaspoon per day
- ○ 1 - 2 teaspoons per day
- ○ 3 - 4 teaspoons per day
- ○ 5 or more teaspoons per day

7. Which cold breakfast cereal do you usually eat?

- ○ Never eat cold breakfast cereal

8. Where do you usually eat breakfast?

- ○ At home
- ○ At school
- ○ Don't eat breakfast
- ○ Other

9. How many times each week (including weekdays and weekends) do you usually eat breakfast <u>prepared away from home</u>?

- ○ Never or almost never
- ○ 1 - 2 times per week
- ○ 3 - 4 times per week
- ○ 5 or more times per week

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10. **How many times each week (including weekdays and weekends) do you usually eat lunch prepared away from home?**

- ○ Never or almost never
- ○ 1 - 2 times per week
- ○ 3 - 4 times per week
- ○ 5 or more times per week

11. **How many times each week do you usually eat after-school snacks or foods prepared away from home?**

- ○ Never or almost never
- ○ 1 - 2 times per week
- ○ 3 - 4 times per week
- ○ 5 or more times per week

12. **How many times each week (weekdays and weekends) do you usually eat dinner prepared away from home?**

- ○ Never or almost never
- ○ 1 - 2 times per week
- ○ 3 - 4 times per week
- ○ 5 or more times per week

13. **How many times per week do you prepare dinner for yourself (and/or others in your house)?**

- ○ Never or almost never
- ○ Less than once per week
- ○ 1 - 2 times per week
- ○ 3 - 4 times per week
- ○ 5 or more times per week

14. **How often do you have dinner that is ready made, like frozen dinners, Spaghetti-O's, microwave meals, etc.**

- ○ Never/less than once per month
- ○ 1 - 2 times per week
- ○ 3 - 4 times per week
- ○ 5 or more times per week

15. **How many times each week (including weekdays and weekends) do you eat late night snacks prepared away from home?**

- ○ Never/less than once per month
- ○ 1 - 2 times per week
- ○ 3 - 4 times per week
- ○ 5 or more times per week

16. **How often do you eat food that is fried at home, like fried chicken?**

- ○ Never/less than once per week
- ○ 1 - 3 times per week
- ○ 4 - 6 times per week
- ○ Daily

17. **How often do you eat fried food away from home (like french fries, chicken nuggets)?**

- ○ Never/less than once per week
- ○ 1 - 3 times per week
- ○ 4 - 6 times per week
- ○ Daily

DIETARY INTAKE

How often do you eat the following foods:

Example If you drink one can of diet soda 2 - 3 times per week, then your answer should look like this:

E1. Diet soda (1 can or glass)

- ○ Never
- ○ 1 - 3 cans per month
- ○ 1 can per week
- ● 2 - 6 cans per week
- ○ 1 can per day
- ○ 2 or more cans per day

BEVERAGES

FILL OUT ONE BUBBLE FOR EACH FOOD ITEM

18. Diet soda (1 can or glass)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 cans per month
- ◯ 1 can per week
- ◯ 2 - 6 cans per week
- ◯ 1 can per day
- ◯ 2 or more cans per day

19. Soda - not diet (1 can or glass)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 cans per month
- ◯ 1 can per week
- ◯ 2 - 6 cans per week
- ◯ 1 can per day
- ◯ 2 or more cans per day

20. Hawaiian Punch, lemonade, Koolaid or other non-carbonated fruit drink (1 glass)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 glasses per month
- ◯ 1 glass per week
- ◯ 2 - 4 glasses per week
- ◯ 5 - 6 glasses per week
- ◯ 1 glass per day
- ◯ 2 or more glasses per day

21. Iced Tea - sweetened (1 glass, can or bottle)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 glasses per month
- ◯ 1 - 4 glasses per week
- ◯ 5 - 6 glasses per week
- ◯ 1 or more glasses per day

22. Tea (1 cup)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 cups per month
- ◯ 1 - 2 cups per week
- ◯ 3 - 6 cups per week
- ◯ 1 or more cups per day

23. Coffee - not decaf. (1 cup)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 cups per month
- ◯ 1 - 2 cups per week
- ◯ 3 - 6 cups per week
- ◯ 1 or more cups per day

24. Beer (1 glass, bottle or can)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 cans per month
- ◯ 1 can per week
- ◯ 2 or more cans per week

25. Wine or wine coolers (1 glass)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 glasses per month
- ◯ 1 glass per week
- ◯ 2 or more glasses per week

26. Liquor, like vodka or rum (1 drink or shot)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 drinks per month
- ◯ 1 drink per week
- ◯ 2 or more drinks per week

Example If you eat:

3 pats of margarine on toast
1 - 2 pats of margarine on sandwich
1 pat of margarine on vegetables

5 - 6 pats total all day

then answer this way →

E2. Margarine (1 pat) - not butter
- ◯ Never
- ◯ 1 - 3 pats per month
- ◯ 1 pat per week
- ◯ 2 - 6 pats per week
- ◯ 1 pat per day
- ◯ 2 - 4 pats per day
- ● 5 or more pats per day

DAIRY PRODUCTS

27. What TYPE of milk do you usually drink?
- ◯ Whole milk
- ◯ 2% milk
- ◯ 1% milk
- ◯ Skim/nonfat milk
- ◯ Don't know
- ◯ Don't drink milk

28. Milk (glass or with cereal)
- ◯ Never/less than 1 per month
- ◯ 1 glass per week or less
- ◯ 2 - 6 glasses per week
- ◯ 1 glass per day
- ◯ 2 - 3 glasses per day
- ◯ 4+ glasses per day

29. Chocolate milk (glass)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 glasses per month
- ◯ 1 glass per week
- ◯ 2 - 6 glasses per week
- ◯ 1 - 2 glasses per day
- ◯ 3 or more glasses per day

30. Instant Breakfast Drink (1 packet)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

31. Whipped cream
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

32. Yogurt (1 cup) - Not frozen
- ◯ Never/less than 1 per month
- ◯ 1 - 3 cups per month
- ◯ 1 cup per week
- ◯ 2 - 6 cups per week
- ◯ 1 cup per day
- ◯ 2 or more cups per day

33. Cottage or ricotta cheese
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 or more times per week

34. Cheese (1 slice)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 slices per month
- ◯ 1 slice per week
- ◯ 2 - 6 slices per week
- ◯ 1 slice per day
- ◯ 2 or more slices per day

35. Cream cheese
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 or more times per week

36. What TYPE of yogurt, cottage cheese & dairy products (besides milk) do you use mostly?
- ◯ Nonfat
- ◯ Lowfat
- ◯ Regular
- ◯ Don't know

37. Butter (1 pat) - NOT margarine
- ◯ Never/less than 1 per month
- ◯ 1 - 3 pats per month
- ◯ 1 pat per week
- ◯ 2 - 6 pats per week
- ◯ 1 pat per day
- ◯ 2 - 4 pats per day
- ◯ 5 or more pats per day

38. Margarine (1 pat) - NOT butter
- ◯ Never/less than 1 per month
- ◯ 1 - 3 pats per month
- ◯ 1 pat per week
- ◯ 2 - 6 pats per week
- ◯ 1 pat per day
- ◯ 2 - 4 pats per day
- ◯ 5 or more pats per day

39. What FORM and BRAND of margarine does your family usually use?
- ◯ None
- ◯ Stick
- ◯ Tub
- ◯ Squeeze (liquid)

→ WHAT SPECIFIC BRAND AND TYPE (LIKE "PARKAY CORN OIL SPREAD")?

Leave blank if you don't know.

40. What TYPE of oil does your family use at home?
- ◯ Canola oil
- ◯ Corn oil
- ◯ Safflower oil
- ◯ Olive oil
- ◯ Vegetable oil
- ◯ Don't know

0	0	0
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9

MAIN DISHES

41. Cheeseburger (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 - 4 per week
- ◯ 5 or more per week

42. Hamburger (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 - 4 per week
- ◯ 5 or more per week

43. Pizza (2 slices)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

44. Tacos/burritos (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 - 4 per week
- ◯ 5 or more per week

45. Which taco filling do you usually have:
- ◯ Beef & beans
- ◯ Beef
- ◯ Chicken
- ◯ Beans

46. Chicken nuggets (6)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

47. Hot dogs (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 - 4 per week
- ◯ 5 or more per week

48. Peanut butter sandwich (1) (plain or with jelly, fluff, etc.)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 - 4 per week
- ◯ 5 or more per week

49. Chicken or turkey sandwich (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 or more per week

50. Roast beef or ham sandwich (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 or more per week

51. Salami, bologna, or other deli meat sandwich (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 or more per week

52. Tuna sandwich (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 per month
- ◯ One per week
- ◯ 2 or more per week

53. Chicken or turkey as main dish (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

54. Fish sticks, fish cakes or fish sandwich (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 or more times per week

55. Fresh fish as main dish (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

56. Beef (steak, roast) or lamb as main dish (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

57. Pork or ham as main dish (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

58. Meatballs or meatloaf (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

59. Lasagna/baked ziti (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 or more times per week

60. Macaroni and cheese (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 or more times per week

61. Spaghetti with tomato sauce (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 - 4 times per week
- ◯ 5 or more times per week

62. Eggs (1)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 eggs per month
- ◯ One egg per week
- ◯ 2 - 4 eggs per week
- ◯ 5 or more eggs per week

63. Liver: beef, calf, chicken or pork (1 serving)
- ◯ Never/less than 1 per month
- ◯ Less than once per month
- ◯ Once per month
- ◯ 2 - 3 times per month
- ◯ Once per week or more

64. Shrimp, lobster, scallops (1 serving)
- ◯ Never/less than 1 per month
- ◯ 1 - 3 times per month
- ◯ Once per week
- ◯ 2 or more times per week

65. French toast (2 slices)
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 or more times per week

66. Grilled cheese (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 or more times per week

67. Eggrolls (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 or more times per week

MISCELLANEOUS FOODS

68. Brown gravy
- ○ Never/less than 1 per month
- ○ Once per week or less
- ○ 2 - 6 times per week
- ○ Once per day
- ○ 2 or more times per day

69. Ketchup
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

70. Clear soup (with rice, noodles, vegetables) 1 bowl
- ○ Never/less than 1 per month
- ○ 1 - 3 bowls per month
- ○ 1 bowl per week
- ○ 2 or more bowls per week

71. Cream (milk) soups or chowder (1 bowl)
- ○ Never/less than 1 per month
- ○ 1 - 3 bowls per month
- ○ 1 bowl per week
- ○ 2 - 6 bowls per week
- ○ 1 or more bowls per day

72. Mayonnaise
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 6 times per week
- ○ Once per day

73. Low calorie/fat salad dressing
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 6 times per week
- ○ Once or more per day

74. Salad dressing (not low calorie)
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 6 times per week
- ○ Once or more per day

75. Salsa
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 6 times per week
- ○ Once or more per day

76. How much fat on your beef, pork, or lamb do you eat?
- ○ Eat all
- ○ Eat some
- ○ Eat none
- ○ Don't eat meat

77. When you have chicken or turkey, do you eat the skin?
- ○ Yes
- ○ No
- ○ Sometimes

BREADS & CEREALS

78. Cold breakfast cereal (1 bowl)

- Never/less than 1 per month
- 1 - 3 bowls per month
- 1 bowl per week
- 2 - 4 bowls per week
- 5 - 7 bowls per week
- 2 or more bowls per day

79. Hot breakfast cereal, like oatmeal, grits (1 bowl)

- Never/less than 1 per month
- 1 - 3 bowls per month
- 1 bowl per week
- 2 - 4 bowls per week
- 5 - 7 bowls per week
- 2 or more bowls per day

80. White bread, pita bread, or toast (1 slice)

- Never/less than 1 per month
- 1 slice per week or less
- 2 - 4 slices per week
- 5 - 7 slices per week
- 2 - 3 slices per day
- 4+ slices per day

81. Dark bread (1 slice)

- Never/less than 1 per month
- 1 slice per week or less
- 2 - 4 slices per week
- 5 - 7 slices per week
- 2 - 3 slices per day
- 4+ slices per day

82. English muffins or bagels (1)

- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 4 per week
- 5 or more per week

83. Muffin (1)

- Never/less than 1 per month
- 1 - 3 muffins per month
- 1 muffin per week
- 2 - 4 muffins per week
- 5 or more muffins per week

84. Cornbread (1 square)

- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more per week

85. Biscuit/roll (1)

- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 4 per week
- 5 or more per week

86. Rice

- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more times per week

87. Noodles, pasta

- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more times per week

88. Tortilla - no filling (1)

- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 4 per week
- 5 or more per week

89. Other grains, like kasha, couscous, bulgur

- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 or more times per week

90. Pancakes (2) or waffles (1)

- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 or more times per week

91. French fries (large order)

- Never/less than 1 per month
- 1 - 3 orders per month
- 1 order per week
- 2 - 4 orders per week
- 5 or more orders per week

92. Potatoes - baked, boiled, mashed

- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more times per week

78 79 80 81 82 83 84 85 86 87 88 89 90 91 92

FRUITS & VEGETABLES

93. Raisins (small pack)
- Never/less than 1 per month
- 1 - 3 times per month
- 1 per week
- 2 - 4 times per week
- 5 or more times per week

94. Grapes (bunch)
- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more times per week

95. Bananas (1)
- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 4 per week
- 5 or more per week

96. Cantaloupe, melons (1/4 melon)
- Never/less than 1 per month
- 1 - 3 times per month
- 1 per week
- 2 or more times per week

97. Apples (1) or applesauce
- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 6 per week
- 1 or more per day

98. Pears (1)
- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 6 per week
- 1 or more per day

99. Oranges (1), grapefruit (1/2)
- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 6 per week
- 1 or more per day

100. Strawberries
- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 or more times per week

101. Peaches, plums, apricots (1)
- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 or more per week

102. Orange juice (1 glass)
- Never/less than 1 per month
- 1 - 3 glasses per month
- 1 glass per week
- 2 - 6 glasses per week
- 1 glass per day
- 2 or more glasses per day

103. Apple juice and other fruit juices (1 glass)
- Never/less than 1 per month
- 1 - 3 glasses per month
- 1 glass per week
- 2 - 6 glasses per week
- 1 glass per day
- 2 or more glasses per day

104. Tomatoes (1)
- Never/less than 1 per month
- 1 - 3 per month
- 1 per week
- 2 - 6 per week
- 1 or more per day

105. Tomato/spaghetti sauce
- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more times per week

106. Tofu
- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more times per week

107. String beans
- Never/less than 1 per month
- 1 - 3 times per month
- Once per week
- 2 - 4 times per week
- 5 or more times per week

108. Beans/lentils/soybeans
- ○ Never/less than 1 per month
- ○ Once per week or less
- ○ 2 - 6 times per week
- ○ Once per day

109. Broccoli
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

110. Beets (not greens)
- ○ Never/less than 1 per month
- ○ Once per week or less
- ○ 2 or more times per week

111. Corn
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

112. Peas or lima beans
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

113. Mixed vegetables
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

114. Spinach
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once a week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

115. Greens/kale
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

116. Green/red peppers
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once a week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

117. Yams/sweet potatoes (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once a week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

118. Zucchini, summer squash, eggplant
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

119. Carrots, cooked
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

120. Carrots, raw
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

121. Celery
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

122. Lettuce/tossed salad
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 6 times per week
- ○ One or more per day

123. Coleslaw
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 or more times per week

124. Potato salad
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 or more times per week

Think about your usual snacks. How often do you eat each type of snack food.

Example If you eat poptarts rarely (about 6 per year) then your answer should look like this:

E3. Poptarts (1)
- ● Never/less than 1 per month
- ○ 1 - 3 per month
- ○ 1 - 6 per week
- ○ 1 or more per day

SNACK FOODS/DESSERTS

125. Fill in the number of snacks (food or drinks) eaten on school days and weekends/vacation days.

Snacks	School Days					Vacation/Weekend Days				
	NONE	1	2	3	4 OR MORE	NONE	1	2	3	4 OR MORE
Between breakfast and lunch	○	○	○	○	○	○	○	○	○	○
After lunch, before dinner	○	○	○	○	○	○	○	○	○	○
After dinner	○	○	○	○	○	○	○	○	○	○

126. Potato chips (1 small bag)
- ○ Never/less than 1 per month
- ○ 1 - 3 small bags per month
- ○ One small bag per week
- ○ 2 - 6 small bags per week
- ○ 1 or more small bags per day

127. Corn chips/Doritos (small bag)
- ○ Never/less than 1 per month
- ○ 1 - 3 small bags per month
- ○ One small bag per week
- ○ 2 - 6 small bags per week
- ○ 1 or more small bags per day

128. Nachos with cheese (1 serving)
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 or more times per week

129. Popcorn (1 small bag)
- ○ Never/less than 1 per month
- ○ 1 - 3 small bags per month
- ○ 1 - 4 small bags per week
- ○ 5 or more small bags per week

130. Pretzels (1 small bag)
- ○ Never/less than 1 per month
- ○ 1 - 3 small bags per month
- ○ 1 small bags per week
- ○ 2 or more small bags per week

131. Peanuts, nuts (1 small bag)
- ○ Never/less than 1 per month
- ○ 1 - 3 small bags per month
- ○ 1 - 4 small bags per week
- ○ 5 or more small bags per week

132. Fun fruit or fruit rollups (1 pack)
- ○ Never/less than 1 per month
- ○ 1 - 3 packs per month
- ○ 1 - 4 packs per week
- ○ 5 or more packs per week

133. Graham crackers
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ 1 - 4 times per week
- ○ 5 or more times per week

134. Crackers, like saltines or wheat thins
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ 1 - 4 times per week
- ○ 5 or more times per week

135. Poptarts (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 poptarts per month
- ○ 1 - 6 poptarts per week
- ○ 1 or more poptarts per day

136. Cake (1 slice)
- ○ Never/less than 1 per month
- ○ 1 - 3 slices per month
- ○ 1 slice per week
- ○ 2 or more slices per week

137. Snack cakes, Twinkies (1 package)
- ○ Never/less than 1 per month
- ○ 1 - 3 per month
- ○ Once per week
- ○ 2 - 6 per week
- ○ 1 or more per day

138. Danish, sweetrolls, pastry (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 per month
- ○ 1 per week
- ○ 2 - 4 per week
- ○ 5 or more per week

139. Donuts (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 donuts per month
- ○ 1 donut per week
- ○ 2 - 6 donuts per week
- ○ 1 or more donuts per day

140. Cookies (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 cookies per month
- ○ 1 cookie per week
- ○ 2 - 6 cookies per week
- ○ 1 - 3 cookies per day
- ○ 4 or more cookies per day

141. Brownies (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 per month
- ○ 1 per week
- ○ 2 - 4 per week
- ○ 5 or more per week

142. Pie (1 slice)
- ○ Never/less than 1 per month
- ○ 1 - 3 slices per month
- ○ 1 slice per week
- ○ 2 or more slices per week

143. Chocolate (1 bar or packet) like Hershey's or M & M's
- ○ Never/less than 1 per month
- ○ 1 - 3 per month
- ○ 1 per week
- ○ 2 - 6 per week
- ○ 1 or more per day

144. Other candy bars (Milky Way, Snickers)
- ○ Never/less than 1 per month
- ○ 1 - 3 candy bars per month
- ○ 1 candy bar per week
- ○ 2 - 4 candy bars per week
- ○ 5 or more candy bars per week

145. Other candy without chocolate (Skittles) (1 pack)
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

146. Jello
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

147. Pudding
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

148. Frozen yogurt
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

149. Ice cream
- ○ Never/less than 1 per month
- ○ 1 - 3 times per month
- ○ Once per week
- ○ 2 - 4 times per week
- ○ 5 or more times per week

150. Milkshake or frappe (1)
- ○ Never/less than 1 per month
- ○ 1 - 3 per month
- ○ 1 per week
- ○ 2 or more per week

151. Popsicles
- ○ Never/less than 1 per month
- ○ 1 - 3 popsicles per month
- ○ 1 popsicle per week
- ○ 2 - 4 popsicles per week
- ○ 5 or more popsicles per week

152. Please list any other foods that you usually eat at least once per week that are not listed (for example, coconut, hummus, falafel, chili, plantains, mangoes, etc. . .)

FOODS	HOW OFTEN?
a) ______	a) ______
b) ______	b) ______
c) ______	c) ______
d) ______	d) ______

a	b	c	d
0 0 0	0 0 0	0 0 0	0 0 0
1 1 1	1 1 1	1 1 1	1 1 1
2 2 2	2 2 2	2 2 2	2 2 2
3 3 3	3 3 3	3 3 3	3 3 3
4 4 4	4 4 4	4 4 4	4 4 4
5 5 5	5 5 5	5 5 5	5 5 5
6 6 6	6 6 6	6 6 6	6 6 6
7 7 7	7 7 7	7 7 7	7 7 7
8 8 8	8 8 8	8 8 8	8 8 8
9 9 9	9 9 9	9 9 9	9 9 9

a	b	c	d
0 0	0 0	0 0	0 0
1 1	1 1	1 1	1 1
2 2	2 2	2 2	2 2
3 3	3 3	3 3	3 3
4 4	4 4	4 4	4 4
5 5	5 5	5 5	5 5
6 6	6 6	6 6	6 6
7 7	7 7	7 7	7 7
8 8	8 8	8 8	8 8
9 9	9 9	9 9	9 9

THANK YOU FOR COMPLETING THIS SURVEY!

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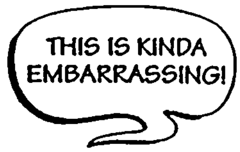
APPENDIX B. 5

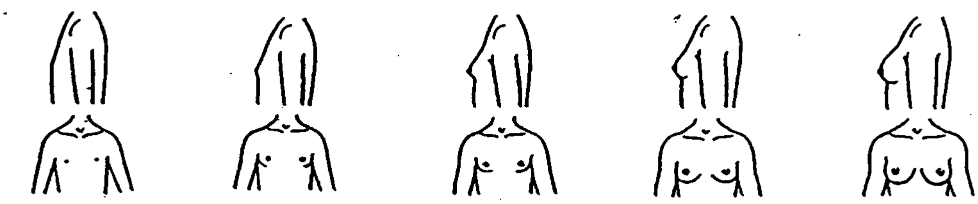
OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
TANNER STAGE LINE DRAWINGS AND WRITTEN EXPLANATIONS

Girls



Girls go through normal changes as they get older. One of these changes is to grow larger breasts. Please LOOK at the drawings and READ the sentences below each of them. Then choose the drawing closest to your stage of breast development and FILL IN THE CIRCLE above it.

STAGE 1 ○ **STAGE 2** ○ **STAGE 3** ○ **STAGE 4** ○ **STAGE 5** ○



Stage 1
- *The nipple is raised a little.*
- *The rest of the breast is still flat.*

Stage 2
- *The breast is a little larger and the nipple is raised more than in Stage 1.*
- *The area around the nipple (areola) is larger than in Stage 1.*

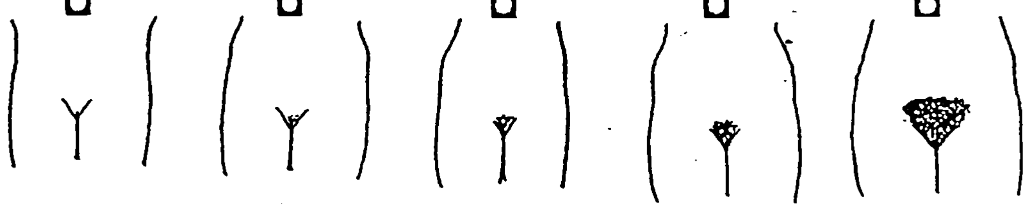
Stage 3
- *The area around the nipple (areola) and the breast are both larger than Stage 2.*
- *The areola does not stick out away from the breast.*

Stage 4
- *The area around the nipple (areola) and the nipple stick up above the shape of the breast.*

Stage 5
- *Only the nipple sticks out in this stage.*
- *The area around the nipple (areola) has moved back down to the breast.*

Another change is to grow pubic hair. Please LOOK at the drawings and READ the sentences below each of them. Then choose the drawing closest to your stage of hair development and FILL IN THE CIRCLE above it.

STAGE 1 ○ **STAGE 2** ○ **STAGE 3** ○ **STAGE 4** ○ **STAGE 5** ○



Stage 1
- *There is no pubic hair.*

Stage 2
- *There is a little, long, lightly colored hair.*
- *This hair may be straight or a little curly.*

Stage 3
- *The hair is darker, coarser, and more curled.*
- *It has spread out and thinly covers a larger area.*

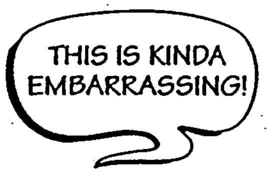
Stage 4
- *The hair is now as dark, curly, and coarse as that of a grown woman.*
- *The hair has not spread out to the legs.*

Stage 5
- *The hair is now like that of a grown woman.*
- *The hair often forms a triangle (▽) as it spreads out to the legs.*

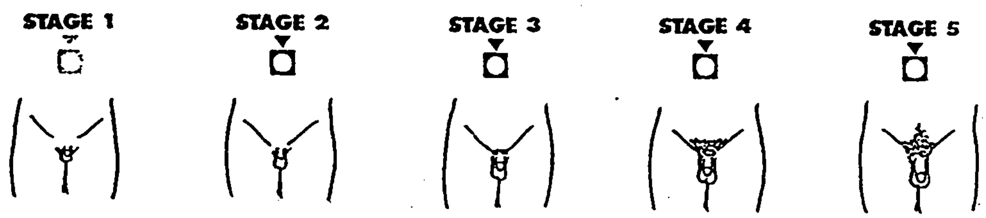
OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY

TANNER STAGE LINE DRAWINGS AND WRITTEN EXPLANATIONS

Boys



Boys go through normal changes as they get older. Please look at the drawings and read the sentences below each of them. Then choose the drawing closest to your stage of hair development and fill in the circle above it.



Stage 1

- *There is no pubic hair.*

Stage 2

- *There is a little soft, long, lightly colored hair.*
- *Most of the hair is at the base of the penis.*
- *This hair may be straight or a little curly.*

Stage 3

- *The hair is darker, coarser and more curled.*
- *It has spread out and thinly covers a larger area.*

Stage 4

- *The hair is now as dark, curly, and coarse as that of a grown man.*
- *The hair has not spread out to the thighs.*

Stage 5

- *The hair has spread out to the thighs, like a grown man.*

APPENDIX C

BODY FAT PREDICTION EQUATIONS

OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
BODY COMPOSITION EQUATIONS

Williams et al., 1992

BODY DENSITY EQUATIONS

Males

White: $-0.00227\ (STSS) + 0.000015\ (STSS^2) + 0.00243\ (age) + 1.0600$

Black: $-0.00203\ (STSS) + 0.000012\ (STSS^2) + 0.00193\ (age) + 1.0682$

Females

White: $-0.00188\ (STSS) + 0.000013\ (STSS^2) + 0.00191\ (age) + 1.0533$

Black: $-0.00162\ (STSS) + 0.000008\ (STSS^2) + 0.00165\ (age) + 1.0580$

BODY FAT EQUATIONS

Boys: $\{(5.68 - (0.041 * age)) / D_b\} - \{(5.31 - (0.045 * age))\} * 100$

Girls: $\{(5.69 - (0.038 * age)) / D_b\} - \{(5.31 - (0.041 * age))\} * 100$

ABBREVIATIONS

STSS = sum of triceps and subscaular skinfolds in mm

D_b = body density