AN ABSTRACT OF THE THESIS OF

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High impact loading activities such as jumping, performed during childhood is advocated as one preventive method for increasing peak bone mass. Thus, we conducted a randomized intervention to examine the effect of high impact loading on bone mass in 34 pre-pubescent boys and girl over a seven month period. Participants meeting all inclusion criteria were randomized into either a jumping (n=18) or stretching group (n=16), both of which exercised three times per week for 15 minutes. The jumping group completed 100 jumps off 24-inch boxes each session, while the stretching group performed low impact flexibility exercises. Attrition was 85% (6 drop outs), with an overall attendance rate of 95%. Bone area and bone mineral content (BMC) was assessed using dual energy x-ray absorptiometery (Hologic QDR 1000/W) for the left hip (femoral neck, greater trochanter, total hip), and lumbar spine ($L_{2-4}$). Other measures were body composition (Lang skinfold calipers); physical activity (self-report questionnaire); and calcium intake (food survey). All measurements were assessed at baseline and 7 months. Significance is denoted as $p < .05$. Analysis of variance (ANOVA) revealed no baseline difference between groups for age, height, weight, body fat, physical activity, or calcium intake ($p > .05$); however, gender differences were found for FN BMC at baseline ($p < .05$). Repeated measures ANOVA identified significant group differences for FN BMC ($p = .015$), with a trend for significance for FN area ($p = .055$). No significant differences in BMC or bone area were found at all other skeletal sites ($p > .05$). No group by gender interactions were found at baseline or at the completion of the seven month intervention. No significant differences between groups were identified for body composition, physical activity, or calcium intake in repeated measures ANOVA analyses ($p > .05$). In conclusion, 100 jumps performed 3 times per week at approximately 8x body weight were sufficient to stimulate an osteogenic response at the femoral neck in pre-pubescent boys and girls. Implementing jumping exercises into regular physical activity programs during pre-pubescent growing years may increase peak bone mass and potentially reduce the onset of osteoporosis.

# The Effects of a 7-Month High Impact Jumping Intervention on Bone Mass in Pre-Pubescent Boys and Girls

by

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Robyn K. Fuchs, Author

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# DEDICATION

*To My Loving Family and Friends*

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

# LIST OF FIGURES

LIST OF TABLES

## LIST OF APPENDICES

# THE EFFECTS OF A 7-MONTH HIGH IMPACT JUMPING INTERVENTION ON BONE MASS IN PRE-PUBESCENT BOYS AND GIRLS

## INTRODUCTION

Osteoporosis and the risk for fractures has become a leading health care concern as it continues to afflict an increasing number of individuals worldwide (Chrischelles, Shireman, and Wallace, 1994; Melton, 1993; Melton, 1996). The reduction in bone strength which typically occurs with age is primarily due to a loss of bone mineral density (BMD), a vital component essential in preserving the integrity of the skeletal system (Marcus, 1996). As we search for preventive measures to reduce the incidence of osteoporotic fractures it is important to consider the implications for both men and women. Although osteoporosis is typically referred to as a disease which afflicts women, men are at risk as well (Mussolino, 1998; Orwoll and Klein, 1993). It is thought that the most effective way to combat osteoporosis may be to increase bone mass during childhood, thus developing a stronger skeletal foundation for later adult years (Bonjour and Rissoli, 1996; Fassler and Bonjour, 1995; Mussolino, Looker, Jennifer, Langlois, and Orwoll, 1998; Slemenda, 1997). Researchers advocate physical activity as one way to increase skeletal mineralization during childhood in an effort to delay the onset of osteoporosis in later adult years (Grimston, Willows, and Hanley, 1993, and Slemenda et al., 1991b). The type of activity best suited for increasing bone mineral accrual is unknown at this time; however, it is thought that high impact loading activities such as gymnastics, volleyball, and basketball are essential for stimulating bone mass accretion during childhood (Cassell, Benedict, and Specker, 1996; Dyson, Blimkie, Davison, Webber, and Adachi, 1997; et al., Grimston et al. 1993; Slemenda et al., 1991b). In addition to the specific loading characteristics needed to promote mineral accrual, the age of which training commences appears to be of equal importance (Lindholm, Hagenfeldt, and Ringert, 1995; Kannus et al., 1995; Etherington et al., 1996). Within this introduction I will discuss factors which are important in developing an exercise regime targeted towards increasing peak bone mass.

Structure and Function of Bone

Utilizing physical activity as a means to increase peak bone mass requires an understanding of the cellular aspects of bone growth during childhood. To start with, I will discuss the basic elements of skeletal modeling in order to develop a framework for which physical activity may stimulate bone mineral accrual. Secondly, I will discuss the manner by which mechanical loading is capable of stimulating bone cells to increase the mineral content in growing bone.

Over the course of the life span the skeletal system undergoes varying degrees of skeletal modeling which consists of the bone building, repairing, and breaking down. To clarify terms, modeling refers to the process of bone formation which occurs as a result of a bone being broken down (resorption) and being built back up (repairing) in specific regions of the skeleton. During childhood, the internal composition of the skeletal system is comprised primarily of a cellular matrix of bone cells called osteoclasts and osteoblast which are responsible for implementing the process of skeletal modeling (Hillman, 1996). Osteoclasts function as bone resorbing cells, and play a key role in the process of bone resorption. Osteoblasts on the other hand are responsible for forming new bone, and are found on the surface of bone. The process of forming new bone involves the secretion of an osteoid material which ultimately forms the new bone. As we age, the process of building bone becomes less efficient which results in the process of resorption taking place at a faster rate than the formation of new bone. This ultimately results in the weakening of the integrity of the skeletal system, and is a contributing factor in determining the onset of osteoporosis. During childhood the process of forming new bone will exceed the process of resorption if a child is provided with adequate nutrition, and opportunities to engage in some form of physical activity that is weight-bearing in nature (Carter, van deer Meulen, and Beaupre, 1996; Slemenda, 1991b) . Thus, in a effort to minimize bone loss, it is believed that interventions need to be implemented during childhood in order to attain a greater supply of bone which can be "saved" for later adult years.

Bone cells play a key role in the capacity for physical activity to yield a positive influence on skeletal mineralization during childhood. Researchers have found that osteoblasts (bone forming cells) are sensitive to mechanical strain applied to bone during various modes of physical activity (Conroy, et al., 1993; Smith and Gilligan, 1996). Depending on the magnitude of the strain, and the nature of the loading patterns for a given activity, a higher level of bone mineral will accrue if the osteoblasts are adequately stimulated. It is important to note that the normal process of bone growth can be inhibited, and modeling activity can be reduced if the type of mechanical strains and loads placed on the skeletal system are too intensive, or performed for an extended period of time (Carter et al., 1996; Forwood & Burr, 1993).

## Peak Bone Mass

Childhood and adolescence is advocated as the most critical period for skeletal mineralization, suggesting that the largest risk for osteoporotic fractures could be attributed to the amount of peak bone mass attained through normal growth, until at least the age of 70 or 75 years (Slemenda et al., 1997). Peak bone mass, defined as the maximum amount of bone mineral content acquired during normal growth is thought to be associated with osteoporotic fractures. Researchers estimate that approximately 60-80% of an individuals total bone mass is attributed to genetics (Forwood and Burr, 1993; Pocock et al., 1997; Slemenda, 1991), with environmental factors accounting for approximately 20-40% of the remaining variance (Gunnes and Lehmann, 1995). Aside from genetic factors which control peak bone mass, researchers have found that adequate calcium intake (Johnston et al., 1992; Pettifor and Moodley, 1997; Ruiz, 1995) and regular weight-bearing physical activity (Daly, Rich, and Klein, 1996; Dyson et al., 1997; Slemenda et al., 1991b Grimston et al., 1994) appear to be key elements in the attainment of peak bone mass.

In the development of preventive strategies targeted towards decreasing the incidence of osteoporosis it is important to determine the age of maximum mineral accrual; however, the exact age of peak bone mass remains unknown. The age of peak skeletal development varies by gender, with women typically attaining peak bone vales at an earlier age than males (Orwoll and Klein, 1995). Estimates of the age of peak bone mass varies, with some researchers advocating peak bone mass to be attained in the second decade of life, where as other researchers estimate peak bone mass reaches a peak during the third and fourth decades of life. Haapasalo and coworkers (1996) found BMC and BMD of the lumbar spine, femoral neck, and greater trochanter to attain peak values between the ages of 18 and 21 in Finish women. This study examined women up to the age of 47 and found that bone loss appeared to begin after the age of 20 at these specific skeletal regions. Theintz and colleagues (1992) found femoral neck and lumbar spine bone mass to peak around the ages of 11 and 14 years in Caucasian females, with Caucasian males peaking around the ages of 13 and 17 at the same skeletal sites. Teegarden and coworkers (1995) examined Caucasian females between the ages of 11 and 32 and found that by the age of approximately 22, 99% of peak bone mineral density was attained, and by approximately age 26, 99% of bone mineral content was attained. On the other hand, work by Faulkner and coworkers (1996) found that BMC and BMD leveled off in women during the ages of 16 and 21. Lastly, work by Lu and coworkers (1994) found that BMD of the total body, lumbar spine, and femoral neck peaked at the age of 17.5 years in males, and 15.8 in women, with the exception of the femoral neck in females which peaked at the age 14.

Gender Differences During Childhood

Determining the age of peak bone mass attainment warrants an examination of gender differences that transpire during childhood and adolescence. Differences in the onset of puberty differ between males and females, resulting in peak bone mass being attained at different time periods. Girls are noted to have accelerated bone growth during the ages of menarche (11-13 years), whereas males appear to have accelerated growth between the ages of 13 and 17 (DeSchepper, Derde, Van den Broeck, Pepsz, and Jonckheer; Glastre et al., 1990; Faulkner et al., 1996; Hillman, 1996; Kroger, Kotaniemi, Kroger, and Alhava, 1993; Rubin et al., 1993).

Although there is generally no association between bone mass and gender during childhood; certain skeletal sites such as the femoral neck have identifiable gender differences. The femoral neck presents an interesting skeletal region with regards to differences among genders. Researchers have found gender differences to be apparent across all ages for both BMC and BMD of the femoral neck (Faulkner et al., 1996; Kroger et al., 1993; Ruiz et al., 1995). Faulkner and coworkers (1996) found that femoral neck BMC and BMD was significantly higher in males compared to females between the ages of 8 and 17. Similar to the work by Faulkner (1996), Kroger and coworkers (1993) found males to display greater femoral neck BMC and area than girls between the ages of 7 and 20. Within this study, the femoral neck had the greatest increases between the ages of 11 and 13 in females, and 13 and 17 in males. Lastly, Ruiz and coworkers (1995) found femoral neck BMD to be significantly greater in boys than girls during pre-pubertal years. Overall, gender difference found at the femoral neck during childhood may be attributed to the types of activities that males engage in compared to females, or males may be more genetically predisposed to having higher bone mass values at this specific skeletal site.

Gender differences seem to be less apparent at the lumbar spine during childhood. Deschepper and coworkers (1991) examined children between the ages of one and 18 years of age and found no gender differences for BMC at the lumbar spine during both prepubertal and pubertal stages of growth. Similar to DeSchepper (1991), Glastre et al. (1990) found that Caucasian boys and girls between the ages of one and 15 did not exhibit significantly different BMD of the lumbar spine until the age of 12, at which point girls were found to have significantly greater spinal BMD. This difference in genders was correlated with pubertal status. Rubin et al. (1993) found that boys and girls between the ages of 6 and 11 had similar lumbar spine BMD; however, after the age of 11, girls were found to have higher lumbar spine BMD than boys. Kroger et al. 1993 found females to have the greatest increases in spinal BMD between the ages of 11 and 13 years, and males had the greatest increase in spinal BMD between the ages of 13 and 17. Lastly, Zanchetta, Olotkin, and Fitgueira (1995) found that boys and girls had similar lumbar spine bone mineral density values between the ages of 2-13. After the age of 13 males were found to have higher lumbar spine BMD than females.

In addition to investigating gender differences at regional sites such as the femoral neck and lumbar spine, researchers have examined differences with respect to total whole body bone mass. Work by Faulkner and Coworkers (1996) found no gender differences for total body BMC and BMD until the age of 14 for BMC, and 17 for BMD at which point males had significantly higher bone values. Additionally, Molgaard, Thomsen, Prentice, Cole, and Michaelsen (1997) found that girls and boys had similar total body bone BMC between the ages of 6 and 11. However, by the age 11 girls were identified as having higher BMC and bone area than boys between the ages of 11-15. By the age of 18.5 bone area was found to be 12% higher in boys and BMC was found to be 21% higher in boys.

## Nutritional Factors Associated with Bone Mass

Several factors such as genetics, nutrition, and weight-bearing physical activity influence the attainment of peak bone mass (Houtkooper, et al., 1995; Johnston et al., 1992; Slemenda, etal., 1991; Vandenbergh et al., 1995). Of these, proper nutritional intake is an important component in the attainment of peak bone mass. Calcium and vitamin D (1,25(OH)2D) are the two primary minerals responsible for attaining optimal mineral accrual (Feldman, Malloy, and Gross, 1996). Vitamin D is a major regulator of both bone formation and resorption. Subclinical vitamin D deficiency is considered to be a primary risk factor for osteoporosis, along with other bone mineral disorders. Sufficient amounts of vitamin D (>200 IU/day) are needed in either an endogenous form (sunlight), or from dietary intake in order to enhance calcium and phosphate absorption. If calcium is unable to be absorbed, this results in an inadequate amount of mineral being deposited at bone forming sites. Seasonal fluctuations in circulating levels of vitamin D can have significant effects on regulating bone mass accrual, and maintaining adequate levels of circulating hormones that regulate bone formation and development. Deficiencies in dietary vitamin D has been positively associated with BMD, particularly during wintertime seasons (Dawson-Hughes, 1989; Docio et al., 1998; Feldman et al., 1996; Krall, Sahyoun, Tannenbaum, Dallal, and). Seasonal fluctuations in vitamin D have typically shown a decrease in circulating vitamin D during winter months, with increases during summer months (Krall et al., 1989). Thus, significant fluctuations in BMD can be found at the femoral neck and lumbar spine depending on the season at which measurements are taken (Krall et al., 1989; Feldman et al., 1996).

The influence of calcium on regulating bone mineral accrual is equally important in the attainment of peak bone mass (Chan, Hoffman, and McMurry, 1995; Johnston et al., 1992; Gunnes and Lehmann, 1995; Matkovic et al., 1995. A diet deficient in calcium will result in lower bone mass values, and a reduction in the acquisition of peak bone mass (Parsons, et al., 1997; Marcus, 1995). If calcium falls below a critical threshold, skeletal mineralization becomes reduced. Although inadequate calcium intake has not been found to inhibit the growth of the skeletal system, it can result in the bone having a thinner cortex (outer shell) with thinner trabeculae (inner structural matrix). During normal growth bone formation is occurring at a greater rate than bone resorption; however, if calcium intake falls below optimal levels the process of formation decreases, and the process of resporption increases (Hillman et al., 1996). During childhood it is recommended that boys and girls intake between 800 and 1,000 mg of calcium per day, where as during adolescence calcium requirements are increased to 1,200 mg of calcium per day. Some researchers have found that a diet lacking in calcium can be counteracted by performing weight-bearing physical activity, resulting in an increased level of bone mineral content (Welten et al. 1994; Ruiz, et al., 1995). On the other hand some researchers have indicated that physical activity is unable to exert an effect on BMD if calcium levels fall below 1000 mg/day (Specker, 1996). Nevertheless, incorporating calcium into a child's diet is important regardless of the potential ability for physical activity to exert a greater influence on bone mass than calcium intake.

## Mechanical Loading and Bone Mass

In addition to obtaining adequate nutrition during critical years of growth, physical activity is viewed as another important element associated with peak bone mass attainment. The mechanical loading characteristics of a specific exercise aide in the organization of the internal structure of growing bone (Carter et al., 1996). Hence, during normal daily activities the mechanical demands imposed upon the skeletal system are characteristically low in magnitude (strain), and apply a limited force to the bone. The integrity of the skeletal system of a growing child can be optimized by incorporating activities that differ from "normal" loading patterns applied to the skeleton. New bone formation has been found to accrue as a result of increasing both the magnitude of strain generated by a specific activity, and increasing the rate at which a load is applied (Conroy et al., 1993; Rubin and Lanyon, 1985). Therefore, unique loading patterns appear to be important to consider when developing exercise regimes targeted towards increasing bone mass during childhood.

Quantitatively speaking, the mechanostat theory was devised which indicates that a minimum effective strain (MES) must be exceeded in order to initiate the modeling process of bone (Frost, 1992, 1993). The mechanostat theory infers that greater than normal loads must be applied to the skeletal system in order to effectively simulate bone to increase either in size or mineral content (Frost, 1992, 1993). Heinonen, Sievanen, Kannus, Oja and Vuori (1996) stated that if normal mechanical strains remain between 200μ and 2500μ the integrity of the skeletal structure will be maintained, without an increase in bone mineral density. However, if loading is increased to a level of strain that exceeds "normal" MES values, it is thought that bone would respond by increasing the process of remodeling. To date, the minimum effective strain needed to alter the conformation of a child's bone mass and geometrical structure have not been examined. Grimston and coworkers (1993) indicated that although the MES principle has not been directly applied to growing bone, biomechanical force data calculated on children between the ages of 10 and 16 years may help describe the loads transmitted by children who perform different activities. The forces imparted by jumping, gymnastics, and running may be significant enough to exceed the MES of a child, and therefore stimulate the modeling process (Grimston et al., 1993). Investigators have found that children have similar ground reaction forces imposed on the skeletal system from impact activities such as jumping (10x body weight) and running (2-5x body weight) as adults (Grimston et al., 1993). Heinonen and Coworkers (1993) found similar loads in running 2-5 times body weight, plus compressive forces due to weight lifting between 18-36 times body weight in adults. It would be expected that children would respond to the loads applied to the skeletal system in a similar manner to that of an adult.

Physical Activity and Bone mass

The effects of exercise on growing bone is believed to be more beneficial than older bone to the greater ability for young bone to adapt to various stimuli elicited through mechanical loading. (Carter, et al., 1996; Forwood and Burr 1993). Overtime numerous researchers have found a positive correlation between physical activity and higher skeletal mineralization; however, this has primarily been inferred through cross-sectional and longitudinal observational studies (Alfredson, Nordstrom, and Lorentzon, 1997; Cassell et al. 1996; Dyson et al. 1997; Fehling, Alekel, Llaey, Rector, and Stillman, 1995; Grimston et al., 1993; Heinonen et al., 1996; Nichols, et al., 1996; Nordstrom et al., 1997; Slemenda, et al. 1991; Slemenda, et al., 1993). The first study reporting a positive association between physical activity and bone mass concluded that weight bearing activities produce notably higher gains in bone mineral density that non-weight bearing activities such as swimming and biking (Slemenda et al., 1991b). Increases in bone mass have been identified in activities which involve higher magnitudes of skeletal loading, such as gymnastics and weightlifting (Cassell et al., 1996; Dyson et al, 1997; Heinonen et al., 1995; Nichols et al., 1991).

Work by Grimston and coworkers (1993) was instrumental in determining the types of mechanical loading necessary to increase bone mass in the immature skeleton of a children. Sports which transmit loads to the skeleton which are greater than 3 times body weight are found to produce significantly greater femoral neck BMD than children involved in active loading sports such as swimming. The long term effect of non-weight bearing activities such as swimming does not appear to be significant enough to induce changes in either BMD or BMC at any skeletal site. (Cassell et al., 1996; Courteix et al., 1997; Grimston et al., 1993; Taaffee et al., 1995). Grimston and coworkers (1993) indicated that although swimming and other non-weight bearing activities do not significantly load the skeletal system, this does not imply that these activities retard growth or inhibit the skeletal system from developing properly. In support of Grimston's work , VandenBergh, Deman and Jacqueline (1995) discovered that children who participate in activities considered to be high impact physical activities had considerably higher bone mass than their counterparts who engaged in only "low impact physical activities". Therefore, not only is the type of activity important for increasing and or maintaining bone mineralization, but the nature of the loading characteristics of a particular activity is an important component as well. (Conroy et al., 1994; Theintz, Howals, Weiss & Sizoneko, 1993; Vandenbergh et al., 1995).

To date, an extensive amount of cross-sectional and longitudinal observational research has examined the loading characteristics of different sports across several different age populations. Heinonen (1995) examined young competitive female athletes who engaged in squash, aerobic dance, and speed skating. Of these three sports, squash players had 13.8% higher bone mass than a sedentary reference group, and 16.8% higher femoral neck BMD than a sedentary reference group. Site specific differences in bone mineral density were found at the femoral neck, lumbar spine, and radius between exercises such as squash, tennis, running, and biking. Each of these sports has different loading characteristics, in addition to varying intensity and duration levels. Alfredsons and coworkers (1997) found that female athletes participating in the high-impact sport of volleyball had significantly higher BMD at the greater trochanter 18.8%, Wards 17.9%, femoral neck 15.8%, and lumbar spine 13.2% compared to nonactive controls. Volleyball players are subjected to a lot of high-force landings due to jumping, making quick turns, and frequently changing directions. Similar to the work by Alfredson et al. (1997), Fehling and coworkers (1995) found that female collegiate athletes who participated in volleyball and gymnastics had greater total body and lumbar spine BMD than those athletes who engaged in swimming. The difference was attributed to the fact that volleyball and gymnastics load the skeletal system with high magnitude forces, over a short period of time, whereas swimming produces pre-dominantly muscular forces, with no ground reaction forces.

A positive association between gymnastics training and BMD has been shown among pre-adolescent females (Dyson et al. 1997), adolescent males (Daley, Rich, and Klein, 1996), and collegiate age women (Nichols et al., 1996; Robinson et al., 1995; Taaffe, et al., 1997). Cassell and investigators (1996) found that elite female gymnasts had significantly greater BMD at the hip and spine compared to swimmers between the ages of 7 and 9. Thus, even during childhood swimming does not appear to be an effective mode of exercise to stimulate skeletal mineralization. Similarly, Dyson and coworkers (1997) found female gymnasts between the ages of 7 and 11 to have significantly greater femoral neck, trochanter, and lumbar spine bone mineral density than nonactive controls. The influential effect of gymnastics training on increasing mineral content can also be noted in women with irregular menstrual cycles who typically have higher than normal bone mass. Taafee and coworkers (1995) found elite collegiate swimmers to have significantly lower bone mass than age-matched gymnasts and controls. In this study women who participated in gymnastics training had greater bone mass at the lumbar spine and femoral neck despite reproductive hormone insufficiency. Fehling and coworkers (1995) found that both gymnasts and volleyball players had significantly greater BMD than swimmers when bone values are corrected for both height and weight. However when bone values are compared under absolute conditions, volleyball players have significantly higher BMD of the total body and right and left legs than both the gymnasts and the swimmers (Fehling, et al., 1995).

Researchers have also provided evidence that bone mass can vary from one skeletal region to another depending on the nature of the loads imposed on the skeletal system (Fehling et al., 1995; Grimston et al., 1993; Heinonen et al., 1993). For example, dancing has been found to stimulate mineral accrual at the femoral neck; however, radial bone mass was found to be similar to non-active controls (Young et al., 1994). On the other hand, tennis has been found to have a positive influence on femoral neck and radial bone mineral density of the dominant playing hand. This indicates the specificity and importance of impact loading on the skeletal system, and the need to develop exercise programs that target clinically relevant skeletal sites such as the hip and spine (Kannus et al. 1995; Slemenda et al., 1993). Slemenda and Johnston (1993) found higher BMD values in the legs and pelvis of professional ice skaters compared to non-active controls, with no significant differences in upper body skeletal sites. Ice skating includes movements which require repetitive jumping, twisting, and take off's which stress the lower extremities more than the upper extremities. Wu, Ishizaki, Kato, Kuroda, and Fukashiro (1998) examined the proximal femoral neck in female rhythmic gymnasts to identify the possibility of side to side differences in bone mass. It was found that bone mineral density was higher on the leg used to perform take-off's, than the leg used to land, with reported ground reaction forces of 4.3 times body weight.

Ballet dancing has been examined with respect to bone density by Young, Mormica, Nzmulerd, and Seeman (1994), who identified higher bone mineral density at sites such as the femoral neck which bear more weight than the lumbar spine. Young et al. (1994) suggested that higher bone density values found at weight-bearing sites in dancers may be a results of exercise during pre pubescent years when the skeleton may be more responsive to exercise. Nordstrom and coworkers (1996) found bone mineral density of the humerus, femur, and proximal femur to be significantly higher in adolescence male hockey players compared to a nonnative reference group. The ice hockey players had been training regularly for four years. Over this time period they trained four hours per week the first year up to ten hours per week by the fourth year of training. Furthermore, figure skaters have been shown to have significantly greater bone mass in the lower extremities (femoral neck, calcaneous) than non-skaters (Slemenda, et al., 1993). The types of loads generated by skating include jumps of high magnitude which impact the lower extremity most significantly

Weight-training has displayed both positive and negative increases in BMD in both male and females in both adolescents and adults. Weight-training has been show to increase BMD in both males and females in areas such as the spine, proximal femur and total body, with varying intensities of training (Conroy et al., 1993; Heinonen et al., 1993; Lohman et al., 1995). Conroy and coworkers (1993) identified significantly greater BMD values of the lumbar spine and femoral neck in elite junior weight lifters with an average age of 17 years, as compared to age matched controls. Work by Heinonen and coworkers (1993) found that weight lifters had higher BMD at most skeletal sites compared to other athletic groups. Although some studies have found no positive effect of weight training, Heinonen et al. and other investigators (Dyson et al., 1997; Forwood & Burr, 1993) believe that the amount of years of specific training an individuals has for a particular activity significantly affects the bones response to increasing bone mass.

The influence of weight training in female athletes was investigated by Heinonen et al. (1996), indicating that weight training provides a more osteogenic stimulus than endurance training. Due to the nature of strength training which involves lower repetitions, and higher weight, several cross-sectional studies have found that bone responds in a positive manor with respect to increase bone mineral accrual in both young and older adult populations (Conroy et al., 1994; Heinonen et al., 1996; Vuori, Heinonen & Sievanen, 1994). Additionally, Heinonen and coworkers (1996) noted that weight lifters with an average of 4 years of sport-specific training history, who trained at a higher frequency and intensity exhibit higher BMD than weight lifter who have only had one year of sport specific training.

The importance of physical activity and its relationship to bone mass has also been supported in studies that have examined previous levels of physical activity. Ethrington and coworkers (1996) examined ex-elite female athletes ages 40-65 who participated in either running or tennis. Former athletes were found to have greater BMD at the lumbar spine, femoral neck, and forearm when compared to nonactive controls. This provides indirect evidence of the long-term effect of weight-bearing exercise. Similarly, Teegarden et al. (1996) found that women between the ages of 18-31 who participated in activities of a weight-bearing nature during high-school years had significantly greater BMD and BMC of the total body, femoral neck, and spine. Work by Karlsson, Johnell, and Obrant (1993) found that nationally and internationally ranked weight lifters between the ages of 16 and 54 had significantly greater BMD of the total body, femoral neck, trochanter, and lumbar spine compared to controls.

Body weight is also an important loading factor that has been shown to play influential a role in determining BMD levels, with higher body weights displaying higher BMD values. Hillman (1996) noted that several studies have found steady increases in BMD of the spine and femoral neck with age, but this increase in BMD is found to be more highly correlated with both the height and weight of the child. BMD has also been examined in children who are classified as being obese finding that although obese children appear to have normal BMD for their age, they typically have lower than normal BMD for their expected body weight (DeSchepper, VanDenBroeck and Jonckheer, 1995). Manzoni et al. (1996) found that obese children (ages 5 and 18 years) have increased fat mass, lean mass, and BMC as compared to normal-weight children. These researchers also found that the influence of weight was not as significant for upper extremities as for the lower extremities. This shows the impact of the mechanical loads that are placed on the skeletal system merely from body weight alone. Additionally, work by Cassell et al. (1996) and Conroy et al. (1993) have shown that intensive exercise training in both gymnast and weight lifters does not have a negative effect on BMD due to the high magnitudes of loads and strains that are applied to the despite below normal age predicted body weight and height.

## Animal Studies

Animal studies have provided additional evidence that high-impact loading activities are an effective modulator of bone mineral accrual. Work by Umemura and coworkers (1997) examined the effects of jumping in female rats . Rats were divided into five jump-training groups comprised of 5, 10, 30, 40, and 100 jumps. Jumps were performed 5 days per week, for eight weeks. The height of the boxes was progressively increased to 40 cm. Results of this study found that all jump training groups experienced an increase in the fat free dry weight of the femur and tibia. It is important to note that although 5 jumps was found to be sufficient to stimulate bone hypertrophy, those rats who performed 100 jumps had a higher breaking strength than those rats who performed only 5 jumps per day. The time required to complete 100 jumps was only five minutes, where as animal studies using endurance training take as long as 30 to 60 minutes to complete (van der Wiel et al., 1995).

Umemura and coworkers (1995) have also examined the effects of jump training and running in female rats. In this study the goal was to examine the difference between running and jumping with respect to bone mass. Rats in the jumping group performed 100 jumps per day 5 days per week, and those rats in the running group ran 5 days per week for 30 to 60 minutes. Results found that the fat-free dry weights of the femur and tibia were significantly greater in the jump training group than the running group, and both the jump training and the running training were significantly higher than the sedentary group. This study found that the jump training was almost equally effective on both the young and old rats. Work by Ummera supports work by Rubin and Lanyon (1985) that the number of loading cycles per day can be small, but the load should be of a high magnitude. The rats in this study were estimated to have run 1000 loading cycles per day, where as the jump training rats only had 100 cycles per day. The magnitude of the loads in the running group were much lower than that of the jumping group which is hypothesized as the reason why the jumping group has the most significant gains in fat free dry weight.

Exercise Interventions and Bone mass

To date only one exercise intervention has been conducted in children. Morris and coworkers (1997) conducted a 10-month non-randomized exercise intervention in premenarcheal girls. The design of the program consisted of 10 exercise stations which focused on both upper and lower body resistance exercises. Subjects performed 1 set of the 10 exercises to start and gradually progressed to 3 sets of 10 exercises. The training program used 2-kg dumbbells, elastic bands for resistance, and the subjects own body weight. Results form this study found significant increase in BMC and BMD for the total body, lumbar spine, proximal femur, and femoral neck.

Blimkie and Coworkers (1996) were the first to examine the effects of resistance training on bone mass in post-menarcheal adolescents. The exercises consisted of both upper and lower body exercises performed on a hydraulic resistance machines. The program consisted of 3 exercises session per week during which time four sets of 10-12 reps were performed. The program resulted in a significant increase in overall strength, however there were no significant increase in total body or LS BMC, BMD, or BMAD. Femoral neck bone mineral content was not examined in this study so it is not know if these resistance exercises would have stimulated an osteogenic effect.

Bassey and Ramsdale (1994) were the first to implement an exercise program that incorporated high impact jumping exercises into an aerobics program. The subject population included premenopausal women in their late twenties to early thirties who were self-selected into two different exercise groups. The jumping group (test group) performed 50 jumps per day at home, in addition to 10-15 minutes of jumping and skipping exercises which were incorporated into an aerobic exercise class. The jumps were performed two-legged, landing on the toes. The control group performed a low impact aerobics class which did not included jumping or hopping exercises, and no jumping exercises were performed at home. Results from this study found a 3.4% increase in trochanteric bone mineral density in those women who performed the high-impact exercises.

From the available research on bone loading programs, jumping type exercise appear to stimulate bone growth because of the high magnitude of the load and the quick strain rates that are applied to the skeletal regions being loaded. (Heinonen et al., 1996; Bassey et al., 1994). Although significant BMD increases have been found through various weight training programs in young and adult populations, children will most likely not be exposed to a weight training, especially at an elite level identified by Conroy et al. (1994) and Cassell et al. (1996). Therefore, researchers should develop exercise programs that take a relatively short period of time to complete, and can be easily incorporated in to physical education programs.

## Potential Negative Effects of Physical Activity on Bone Mass

Although exercise has been found to have a positive effect on increasing bone mass, intensive exercise regimes can damage the development of growing bone. Therefore, it becomes necessary to implement interventions designed to effectively increase mineral content without damaging the development of the growing skeletal system. Excessive and intensive training can cause problems such as delayed development, delayed menarche, and increased occurrence of stress fractures (DeSchepper et al., 1995; Lindholm et al., 1995 &; Slemenda & Johnston, 1993). Despite the fact that intensive exercise may lead to delayed menarche, weight bearing activities such as gymnastics and ballet have been found to protect athletes from excessive bone loss (Robinson et al., 1995, Taafee, et al., 1995). Work by Pigeion and coworkers (1997) found that ballet dancers between the ages of 9 to 18 had delayed onset of puberty, and were found to have more eating disorders and weight control problems early in childhood. Due to the intensive nature of many sports it becomes necessary to develop exercise regimes that are short in duration, yet yield positive benefits with regard to increasing bone mass.

Theintz et al. (1993) noted a marked reduction in the overall leg length of elite female gymnasts. Due to the intense nature of the workouts, excessive training was reported to potentially decrease the final height of gymnasts, preventing them from reaching their true growth potential. Due to an increased risk of fracture evident in elite gymnasts, it is important to determine boundaries for what is considered to be an adequate amount of physical activity to induce changes in bone, without affecting growth patterns and menstrual functions. Slemenda et al. (1993) found that women who compete in competitive figure skating between the ages 10-23 had delayed menarche compared to non-active controls. Although the female figure skaters had delayed menarche, they were found to have significantly greater bone mass in the legs and pelvis than non active controls; however there was a trend for skaters with menstrual disorders to have lower bone mass values than normal menstruating skaters. Overall, woman gymnast who have a demanding training schedule are found to have delayed menarche, and subsequently significantly decrease the number of periods once menarche is reached to an  or amenorrheic status. However, the high-impact loads characteristic of these athletes training regimes appears to provide a protective effect against excessive bone loss when growth is delayed and menarche is delayed.

<u>Effects of Detraining on Bone Mass</u>

Bone that is not subject to a significant amount of loading, either from prolonged bed rest, immobilization, or activities non-conducive in promoting bone mineralization results in bone loss. The repercussions of losing significant amounts of bone mass are not as pronounced during childhood, but are more noticeable in older adult women who suffer from either early or late stages of osteoporosis. The lumbar spine, femoral neck, distal femur, and radius are most susceptible to fracturing in later adult years due to the bones inability to handle the compressive forces applied to the bone, and due to the weakening of the integrity of the skeletal system.

Lindholm and coworkers (1995) examined the BMD of former gymnasts to determine how a decrease in both intensity and duration specifically affected bone growth over time. The former gymnasts at one time trained between 10 and 20 hours per week during the pre-pubertal stage of growth and had significantly higher BMD than when they were measured approximately four years later, where the average amount of training time was only 5 hours per week (Lindholm et al., 1995). This decrease in both the intensity and duration allowed most of the gymnast to regain normal height and weight which was a positive factor of the decrease in training. However, due to the decrease in training, bone mineral density dropped back to baseline levels of age matched controls (Lindholm et al., 1995). This is an important study to examine when determine an appropriate exercise regimen for children that will be able to stimulate an adequate amount of growth without affecting the growth and development of the skeletal system. On the other hand, Theintz et al. (1993) found that gymnasts were unable to regain a normal stature of height and body weight even after training was decreased to a minimal level, concluding that the extensive training that gymnasts undergo can be harmful for the growth and development of a child. Overall it is important to develop exercise programs which are efficacious for young children. At this time it is not now how much exercise can be tolerated without causing damage to the growing skeleton.

# MANUSCRIPT

# The Effects of a 7-Month High Impact Jumping Intervention on Bone Mass in Pre-Pubescent Boys and Girls

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# ABSTRACT

An increase in bone mass during growth has been proposed as the best prevention for osteoporosis. Limited cross-sectional reports support exercise as a prevention strategy. To date, high impact loading for increasing bone mass in childhood has not been examined. **Purpose**: The aim of this study was to investigate the effects jumping, a high impact loading activity on bone mass in pre-pubescent boys and girls. **Methods**: 34 pre-pubescent children (18 boys, 16 girls) meeting all inclusion criteria were randomized into either a jumping (n=18) or stretching group (n=16). Both groups exercised three times per week for 15 minutes over a seven-month period. The jumping group completed 100 jumps off 24-inch boxes each session, while the stretching group performed non-impact flexibility exercises for the upper and lower extremities. Jumps were carefully counted and recorded at each exercise session. Bone mineral content (BMC) and bone area was assessed using dual energy x-ray absorptiometery (Hologic QDR 1000/W) for the left hip (femoral neck, greater trochanter, total hip), and lumbar spine ($L_{2-4}$). Other measures were body composition (Lang skinfold calipers); physical activity (self-report questionnaire); and calcium intake (food questionnaire). All measurements were taken at baseline and 7 months. **Results**: Attrition was 85% (6 drop outs), with an overall adherence rate of 95%. Significance is set at $p < .05$. Analysis of variance (ANOVA) revealed no baseline differences between groups for age, height, weight, body fat, physical activity, or calcium intake ($p > .05$); however, gender differences were observed for FN BMC at baseline ($p < .05$). At the completion of the intervention repeated measures ANOVA revealed group differences for FN BMC ($p = .015$), with no significance found for FN area. There were non-significant trends for increases in BMC and bone area at all other regions of the hip, with no trend at the spine. No significant differences between groups were identified for body composition, physical activity, or calcium intake in a repeated measures ANOVA analysis ($p > .05$). No group by gender interactions were found at baseline or at the completion of the seven month intervention. **Conclusion**: The results of this study suggest that 100 jumps performed 3 times per week at approximately 8x body weight were sufficient to stimulate an osteogenic response at the proximal femur in pre-pubescent boys and girls. Implementing jumping exercises into regular physical activity programs during pre-pubescent growing years may increase peak bone mass and reduce the onset of osteoporosis. **Key Words:** BONE AREA, BONE MINERAL CONTENT, JUMPING, EXERCISE, CHILDREN.

# INTRODUCTION

Osteoporosis, characterized by low bone mass and skeletal fragility is associated with over 2 million hip fractures worldwide, with a projected 6.3 million hip fractures by the year 2050 (5,35,36,39). The onset of this disease is silent in nature, and is related to peak bone mass, defined as the maximum amount of bone mineral accrued during normal growth mass (27,53). While the exact timing of peak bone mass attainment is equivocal, it is estimated to occur as early as 14 (22,30,33,59,61). It is estimated that approximately 60-80% of an individuals peak bone mass is correlated with genetics (45,52), with the remaining associated with factors such as nutrition and physical activity (26, 44, 40, 56, 67). As the annual incidence of osteoporotic fractures continues to rise, there is growing support that physical activity during childhood may effectively increase peak bone mass, thus be an important strategy for osteoporosis prevention (20,34, 54, 59).

The association between physical activity and peak bone mass was first examined by Slemenda and coworkers (1991) finding that children who engaged in some form of physical activity had higher bone mineral density than non active children. Overtime, numerous researchers have found that children who engage in high impact loading activities such as gymnastics typically have higher bone mass values than children involved in low-impact activities such as running, and non-impact sports such as swimming (4, 20, 13, 54, 55). Although there appears to be a strong relationship between weight-bearing physical activities and peak bone mass, this relationship is based primarily on observational studies, and the exact mode, frequency, intensity, and duration necessary to stimulate an increase in bone mass during peak growing years remains unknown.

In addition to the type of exercise that is performed, researchers have provided direct evidence that the age at which training commences is critical in maximizing peak bone mass (14, 21, 28, 60). This was first demonstrated by Kannus and coworkers (1995) who found that the starting age of tennis and squash players to be highly correlated with bone mass attainment at the radius and femoral neck. Thus, engaging in physical activity before puberty has been shown to be more osteogenic than beginning after puberty (2, 28, 31, 55, 60).

To date, only one exercise intervention of resistance training has been conducted in children (37). After 10 months of low intensity resistance training Morris and coworkers (1997) reported significant increases of 3.5 to 12% in bone mass in exercising prepubertal girls compared to controls. Although the study was not randomized, the changes reported were higher than those observed in post-menarchal girls (2) and adults women engaged in weight-training (2, 29, 32, 51). Although effective for increasing bone mass, the feasibility of implementing resistance training exercises into physical education programs may be costly and require an extensive amount of time to complete. In order for an exercise program to be an efficacious preventive strategy for reducing the incidence of osteoporosis it is important to design exercises that are easy to perform and only require a short period of time to complete.

Evidence that high-impact loading activities are capable of stimulating bone growth come primarily from animal models and adult populations. Animal models have evaluated very specific protocols and demonstrated that as few as 5 to 100 jumps per day were osteogenic in young female rats (63-65). Bassey and Ramsdale (1994) found that premenopausal women performing 50 jumps per day effectively increased trochanteric bone mass by +3.4%. It has been hypothesized that the growing skeleton is more sensitive to the mechanical loads placed skeletal system than is the older skeleton (3). To date, no prospective intervention study has examined the effects of high-impact loading activities such as jumping in pre-pubescent children.

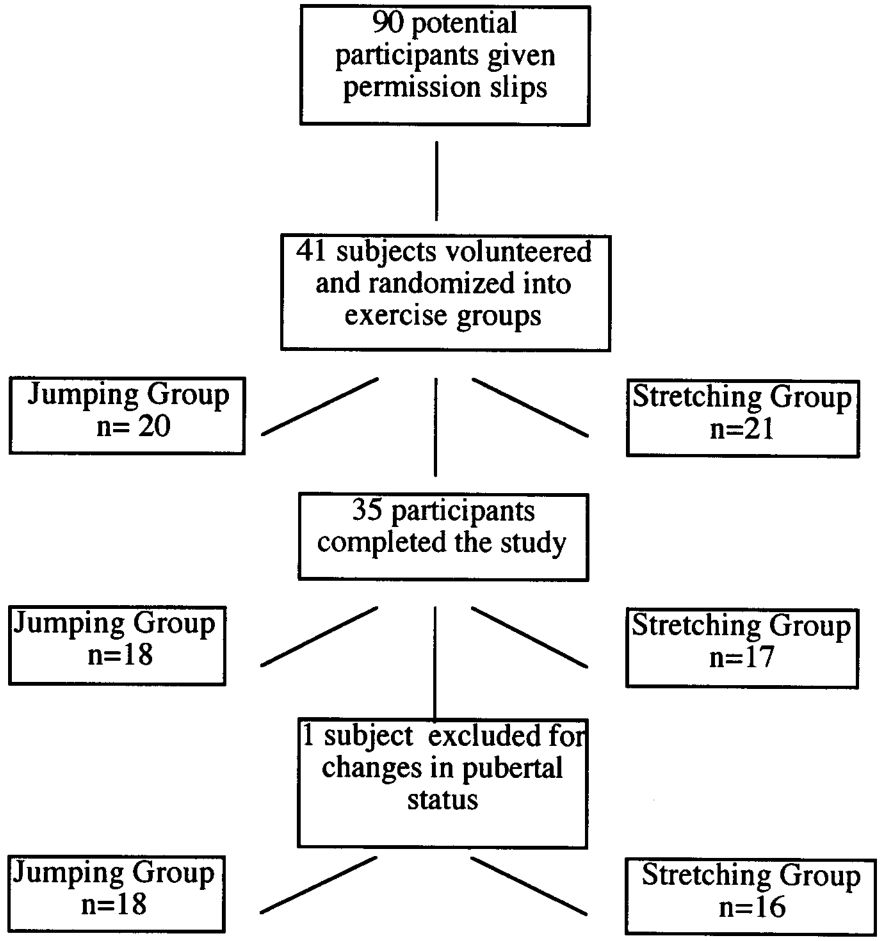
This study investigated the effect of a seven month high impact jumping program on bone mass in pre-pubescent boys and girls. We hypothesized that bone mineral content and bone area at the proximal left femur and lumbar spine ($L_{2-4}$) would be significantly greater in jumpers than stretchers following the seven month intervention. Rationale for the specific intervention employed in this study was based on evidence that high impact loading exercise appears to be the most effective means for increasing bone mass in studies of both an observational (4, 6, 13, 16, 20, 54), and intervention (1, 24, 63, 64) nature.

# METHODS AND PROCEDURES

## Study Design and Subject Recruitment

We conducted a randomized exercise intervention examining the effects of high-impact skeletal loading on bone mass in pre-pubescent children over a period of seven months. Two intact classes of second graders (n=43), and third graders (n=47) from a local elementary school in Corvallis, Oregon participated in the study. All children in both classrooms were randomly assigned to either a jumping group, or a control stretching group. Parents were given the option of including their child in both the testing and exercise intervention, the exercise intervention only, or no participation in the study. Because the intervention was a classroom activity parents were given the option of having their child complete the testing measurements. Radiation exposure was the primary reason for parents not including their child in the study, not the exercise program. Of the 90 children, 41 students were given parental permission to participate in both the testing and exercise intervention, and were randomized into either a jumping (n=21), or stretching (n=20) group. Of these, two children moved, two were unable to come in for post-testing due to time constraints, and two had parents who became concerned about the radiation exposure. At the conclusion of the intervention, the jumping and stretching groups consisted of 18 and 16 participants, respectively. Subjects were scheduled for testing based on the parents availability. Testing was conducted at the Bone Research Laboratory at Oregon State University within a two week period at the end of September (baseline) and end of May (post-testing). This study was approved by the Oregon State University Institutional Review Board and parents of all children gave written informed consent prior to participation.

Figure 1. Participant Flow Chart




Subjects

Thirty-four apparently healthy, pre-pubescent children (18 boys and 16 girls) between the ages of seven and nine years completed this study. The ethnic background of the sample included 28 Caucasian, one Indian, one Asian, and four bi-racial children. All participants lived in the same demographic area in Corvallis, Oregon. The parent of each child completed a standard Health and Physical Activity Questionnaire prior to participation to identify potential exclusion factors. Exclusion criteria included a) disorders, or medications that may affect bone metabolism; b) thyroid disease; c) diabetes; d) chronic diseases or orthopedic problems that may limit training and testing; e) body weight that exceeds 20% of the recommended weight for height and age; f) change in Tanner stage from baseline; and g) the presence of early menarche. Only one participant was excluded from analysis due to Tanner stage changes from 1 (baseline) to 2 (post-intervention).

## Secondary Sexual Characteristics

Tanner stages were used to identify pubertal status using pubic hair in boys, and both pubic hair and breast development in girls. Five stages of pubic hair and breast development were used to classify each participant: 1) pre-pubertal; 2) initial stages of development; 3 - 4) intermediate stages of development; 5) stage of development. (58). Parents were given line drawings and written explanations of each Tanner stage in order to identify their child's stage of development. This method of classifying pubertal development has been found to be highly correlated with classification of pubertal development by physicians (10).

## Anthropometric Measurements

Height and weight were measured in light indoor clothing, without shoes using a Healthometer standard height and weighing scale. Height was measured to the nearest .5 inch and weight was measured to the nearest .5 kg.

A two site (triceps and subscapular) skinfold protocol was used to measure body fat using Lang skinfold calipers. Body fat was calculated using prediction equations developed by Williams et al. 1992. Separate body fat equations were used for boys and girls, and black and white children (68). To date there are no know reported body fat calculations suitable for the other races represented in our sample; therefore, the white body fat equations were employed for all participants in this study. All skin fold testing was performed on the child's right side. The same technician performed all skin fold measurements, and the same calipers were used for baseline and post testing measurements. The coefficient of variation for this technique was 2% for this subject sample.

Bone Measurements

Bone mineral content (g) and bone area ($cm^2$) was assessed by dual energy x-ray absorptiometry (Hologic QDR 1000/W; Waltham, MA) for the left proximal hip (femoral neck, greater trochanter, and total hip), and lumbar spine. Bone measurements obtained using DXA have an in-house precision error of 1-1.5% for the hip and spine. Daily quality control was maintained using a spine phantom provided by Hologic.

Hip scans were performed using a positioning apparatus which held the left leg in an internally rotated position of 30 degrees. The lumbar spine scan was performed with the child positioned in a supine position with the knees elevated on a semi-soft box provided by Hologic, Inc. Scans were re-started if the child moved. All scans were performed and analyzed by the same technician in an effort to minimize interobserver variation. A technician, unaware of subject group was present for the analyses of the bone scans. The width of the femoral neck box remained constant at 11 mm for pre and post scan analyses.

Physical Activity Assessment

Physical activity was assessed using a self-report physical activity questionnaire (54). This questionnaire was developed for boys and girls ages 5 to 14. The parent and child completed this questionnaire together, and the researcher verified all information by re-asking the questions with both the parent and child. Information obtained from this questionnaire included: a) total number of hours per day spent watching television on school and non-school nights, b) mode and duration of physical activity per week; c) participation in team sports; and d) intensity, frequency, and duration of the child's PE class. Physical activity was calculated based on the total number of weight bearing hours performed per week. This calculation only includes weight bearing activities performed outside of school time, and does not include physical education classes or walking. Participants were placed into one of five categories for television viewing based on the total number of hours per day: 1) none; 2) .5-1; 3) 1.5-3; 4) 3.5-5; 5)5+. Time spent watching television was calculated based on the total number of hours of television watched on school and non-school nights per week. Test-retest correlation was reported to be .62 for reported number of weight bearing hours and .60 for hours per week of television viewing (54).

Calcium Intake

Information regarding calcium intake was obtained form the general health and physical activity questionnaire. The following questions were asked: a) how many eight ounce glasses of milk does your child consume per day and per week?; b) how many servings of cheese (1 ounce) does your child eat per day?; c) how many servings of yogurt (1 cup) does your child eat per week? Parents were responsible for answering these questions with their child. The principal investigator of this study was available to answer questions pertaining to serving sizes. Food models were used to aid in estimating serving sizes. Calcium intake was estimated using the following RDA estimates: a) one eight ounce class of milk equals 300 mgs of calcium; b) 1 serving of cheese equals 183 mgs of calcium; and c) once cup of yogurt equals 250 mgs of calcium. It is important to note that the calcium estimates presented in this study only include calcium obtained from dairy products.

Exercise Intervention

The intervention took place from October to May, during which time three weeks were taken off (December) for a winter break, and one week was taken off (March) for a spring break at the elementary school. All participants were involved in regularly scheduled physical education class twice a week for 30 minutes, in addition to 15 minutes of either jumping or stretching exercise class three times per week for 15 minutes. All exercise classes were performed in a large activity room at the elementary school. The exercise intervention was scheduled at different times for the second and third grade classes to limit the number of participants exercising at one time, and to accommodate the teaching schedules of the classroom teachers. All classes included a brief walk for warm up and cool down, and both the jumping and stretching groups had the same exercise instructor for the entire duration of the intervention. The children were asked not to perform the jumping exercises at home, or at any other time outside of the regularly scheduled intervention classes. Instructors of each group maintained a journal that consisted of daily lesson plans, injuries, illnesses, absences, and the specific number of jumps and/or stretches completed.

*Jumping group:* Jumps were performed in a unilateral direction off 24 inch boxes. Participants were instructed only to jump forward off the box, and were asked not to jump up onto the box or perform side to side jumps. Due to the height of the boxes, an eight inch box was placed in front of the 24 inch box to aid participants in stepping onto the 24 inch boxes. The first two weeks of the intervention were spent learning how to perform the jumping exercises according to the following criteria: 1) maintain proper posture (straight back, shoulders back); 2) jump off the box with both feet together; and 3) land with the knees as straight as possible, with both feet together, flat-footed. Participants began with 50 to 80 jumps/day the first two months, and were progressively overloaded to 100 jumps/day for the remaining four months. In order to complete all jumps in a short period of time circuits were designed which consisted of either rows of three to four boxes, or a large circles of seven to eight boxes. The children performed continuous laps around the rows or circles of boxes until the desired number of jumps were completed. In order to ensure an accurate number of jumps were completed the children placed straws, bean bags, and other objects into large baskets after each jump was completed. The format of the jumping classes made it easy for the instructor to record the total number of jumps performed by each participant. It is important to note that all children completed the same number of jumps at each session.

*Stretching group:* Flexibility exercises emphasized the major muscle groups of the body. A total of three to four upper body, and three to four lower body exercises were performed at each session. Stretches were held for a duration of 15-60 seconds, and one to two repetitions of each flexibility exercise were performed. The participants were taught to hold the stretches until the point of mild discomfort. The purpose of the stretching group was to act as a low-impact control group, not to improve flexibility. Therefore, no tests were administered to measure improvements in flexibility. Individuals in the stretching group were asked not perform the jumping exercises at any time during the course of the study.

# STATISTICS

SPSS version 8.0 was used to analyze all data in this study. Data screening was performed to identify potential outliers, missing data, multicolineraity between dependent variables, and to ensure that all data were correctly entered into the spreadsheet. Significance level is reported as p less than .05, and data are presented as mean ± standard deviation.

Univariate analysis of variance (ANOVA) evaluated group, gender, and group by gender differences at baseline for height, weight, body fat, physical activity, television status, calcium intake, BMC and bone area at each skeletal site.

Bivariate correlations, using absolute values were performed at baseline between anthropometric variables, bone area (FN, GrTr, TH, and LS), and BMC (FN, GrTr, TH, and LS). These correlations were accomplished by using absolute values for both the anthropometric and bone variables.

A two (group) x two (time), repeated measures ANOVA for each skeletal site was used to determine main effects of the intervention using pre (baseline) and post (7-months) using pre and post bone values as the main factor, and group as the between subjects factor.

Separate repeated measures ANOVA's were performed by group, gender, and group by gender on anthropometric variables and physical activity at the completion of the intervention in order to examine changes over time.

# RESULTS

## Subject Characteristics

The jumping and stretching groups were similar at baseline for age, height, weight, and body fat, and there were no significant gender differences, or group by gender interactions found for age, height, weight, or body fat at baseline (table 1). Bivariate correlations between height, weight, and body fat revealed no significant associations at baseline ($p > .05$). At baseline, all boys and girls were classified as Tanner stage 1 for pubic hair and breast development.

At the completion of the intervention repeated measures ANOVA revealed no significant differences in age, height, weight, or body fat between groups ($p > .05$), and there were no group differences, or group by gender interactions found at the completion of the intervention for age, height, weight, or body fat (figure 2). Tanner stages remained unchanged from baseline to the completion of the intervention.

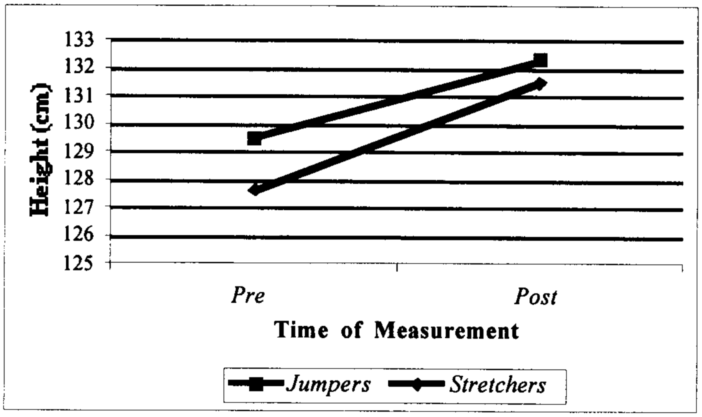
A separate analysis was performed which included the six drop outs in order to identify the generalizability of the subject sample. There were no significant differences found for height, weight, or body fat between groups, and there were no gender differences, or group by gender interactions found ($p > .05$).

Table 1. Baseline Descriptive Characteristics by Group and Gender (mean ± SD).

| | Jumpers (n=18) | Stretchers (n=16) | Boys (n=18) | Girls (n=16) |
|---|---|---|---|---|
| Age (yrs.) | 8.14 ± .66 | 8.06 ± .57 | 8.2 ± .66 | 7.9 ± .56 |
| Height (cm) | 129.54 ± 6.63 | 127.64 ± 7.24 | 129.26 ± 7.52 | 127.95 ± 6.26 |
| Weight (kg) | 29.10 ± 5.80 | 26.79 ± 4.04 | 28.96 ± 5.26 | 26.94 ± 4.88 |
| Body Fat (%) | 18.32 ± 7.20 | 16.73 ± 4.61 | 16.24 ± 6.97 | 19.06 ± 4.69 |

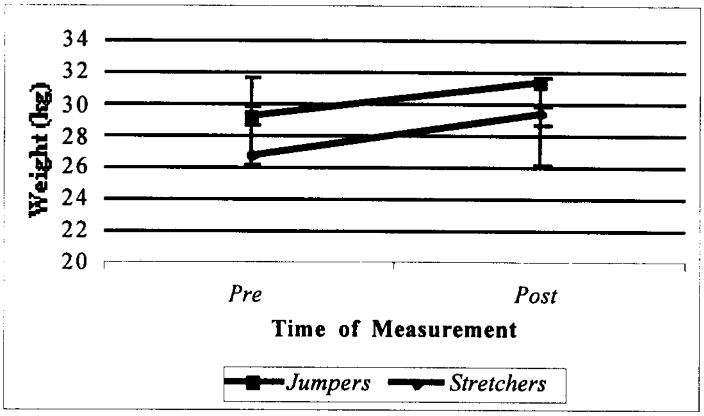
Figure 2. Anthropometic Characteristics by Group for Height (A), Weight (B), and Body Fat (C) Presented as Bbsolute Values at Baseline (pre) and the Completion of the Seven Month Intervention (post).

A



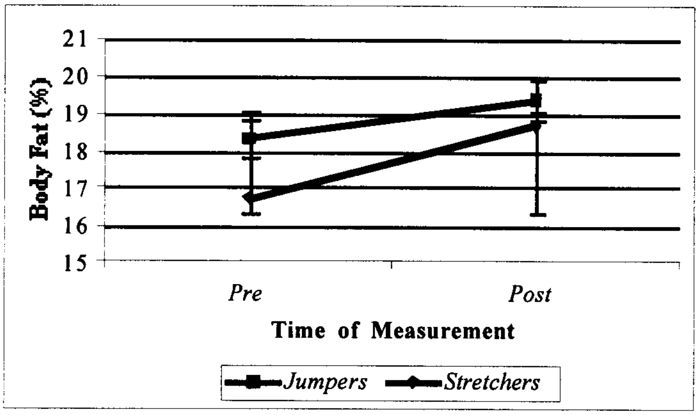

*No significant differences by group found for height at baseline or the completion of the intervention.

B




*No significant differences found by group between weight at baseline or the completion of the intervention.

C




*No significant differences found by group between body fat at baseline or the completion of the intervention.

Program Adherence, Attrition, and Injury Rates

The exercise intervention had an overall attrition rate of 85% due to six drop outs, three from each group. A total of 76 exercise classes were completed during the seven month intervention. There was an overall attendance (adherence) rate of 96% (range of 86-100%). The jumping group had an attendance rate of 95% (range of 86-100%), and the stretching group had an attendance rate of 97% (range of 89-100%). Attendance rates were calculated based on the total number of classes completed by each participant, divided by the total number of exercise classes. Absences were due to illness, injury, vacation, and school related activities. To our knowledge no injuries were incurred during the seven month intervention in either the jumping or stretching group.

Bone Mineral Content and Bone Area Status

Baseline differences for BMC and bone area were not significant between groups for all skeletal sites (figure 3), and there were no group by gender interactions. Boys and girls were similar for BMC and bone area for all skeletal sites except FN BMC which was higher in boys than girls ($p < .05$). Since gender differences were found for FN BMC at baseline, separate repeated measures ANOVA analyses were performed for each gender, using FN BMC as the main factor and group as the between factor. No significant group differences were found when examining each gender separately ($p > .05$), thus randomization was effective. At baseline, in correlation analysis for the entire group height and weight were associated with BMC and bone area for all skeletal sites ($p < .05$). Body fat was not correlated with bone area or BMC for any skeletal site in either group ($p > .05$). Univariate ANCOVA did not reveal significant differences between groups for bone area or BMC when height and weight were entered as covariates ($p > .05$). At baseline, children in the jumping group had attained between 55-85% of their bone mass for the total hip (52-81% at the femoral neck, and 56-87% at the greater trochanter), and 49-72% at the spine, whereas children in the stretching group attained between 54-82% of their bone mass at the hip (55-88% at the femoral neck, and 62-94% at the greater trochanter) and 49-72% at the spine.

At the completion of the seven month intervention repeated measures ANOVA revealed significant group differences for femoral neck BMC, but not area ($p<.04$). No other skeletal sites were significantly different between groups; however, there was a trend for greater trochanter and total hip BMC and bone area to be higher in the jumping compared to the stretching group (figure 3). The effects of the jumping intervention on bone area and BMC are summarized as absolute values in Figures 3 and 4, and percent change and difference scores in table 3. The LS exhibited no significant differences or trends between treatment groups, and there were no gender differences or group by gender interactions found at the LS ($p > .05$).

Percent change, and difference scores are presented in table 3 for bone area and BMC for each group. At the completion of the intervention participants in the jumping group attained between 53-84% of their bone mass at the hip (57-90% at the femoral neck and 59-95% at the greater trochanter), and 49-68% at the spine. Participants in the stretching group attained 58-83% for the total hip (58-88% at the femoral neck and 62-94% at the greater trochanter), and 49-72% at the spine.

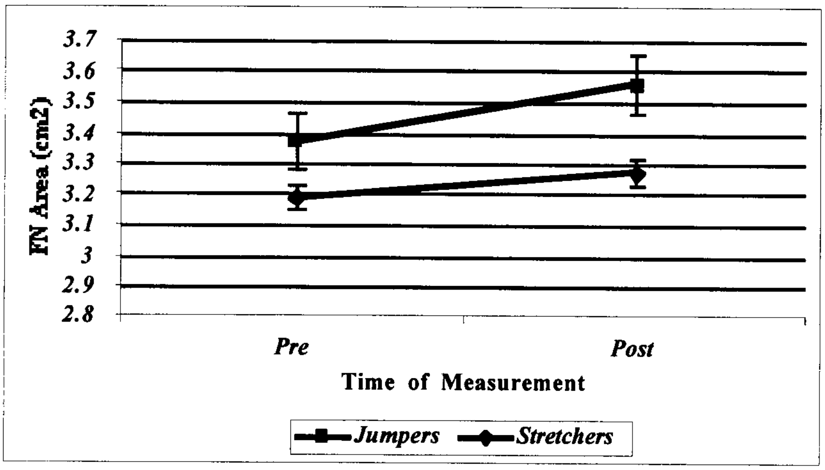
The six drop outs (three from each group) were included in a separate analyses to identify the generalizablity of the bone area and BMC results for the children represented in this study sample. Univariate ANOVA analyses revealed no significant differences between groups for bone area or BMC for all skeletal sites. There were significant gender differences found for FN area and FN BMC; however, it is important to note that one of the drop outs was classified as an outlier for this population based on bone values being greater than two standard deviations above normal for his age group. Removal of this subject eliminated FN area gender differences, with difference found only for FN BMC. This is the same difference found with the 34 participants included in the final analyses.

Table 2. Main Effects of Intervention Presented as Difference Scores (post-pre) and Percent Change (%) Between Groups for Bone Area and Bone Mineral Content at Baseline and the Completion of the Seven Month Intervention (mean ± SD).

| | Jumpers (n=18) | Stretchers (n=16) | p value | Observed Power |
|---|---|---|---|---|
| FN area | | | | |
| Difference Score | .19 ± .12 | .08 ± .19 | .055 | .490 |
| Percent Change | 2.9 ± 3.2 | .966 ± 3.5 | | |
| GrTr area | | | | |
| Difference Score | .61 ± .58 | .49 ± .53 | .564 | .087 |
| Percent Change | 4.17 ± 5.06 | 2.26 ± 3.37 | | |
| TH area | | | | |
| Difference Score | 1.37 ± .81 | 1.06 ± .67 | .244 | .210 |
| Percent Change | 3.37 ± 2.60 | 2.67 ± 3.40 | | |
| LS area | | | | |
| Difference Score | .92 ± .41 | .79 ± .50 | .432 | .121 |
| Percent Change | 4.10 ± 2.79 | 4.01 ± 2.00 | | |
| FN BMC | | | | |
| Difference Score | .19 ± .12 | .06 ± .16 | .015 | .699 |
| Percent Change | 8.02 ± 5.12 | 3.28 ± 7.44 | | |
| GrTr BMC | | | | |
| Difference Score | .48 ± .41 | .35 ± .36 | .323 | .164 |
| Percent Change | 14.35 ± 11.34 | 123.41 ± 13.29 | | |
| TH BMC | | | | |
| Difference Score | 1.43 ± .80 | 1.04 ± .60 | .125 | .333 |
| Percent Change | 9.87 ± 4.96 | 8.62 ± 6.05 | | |
| LS BMC | | | | |
| Difference Score | 1.20 ± .55 | 1.15 ± .56 | .797 | .057 |
| Percent Change | 7.60 ± 3.62 | 6.97 ± 3.22 | | |

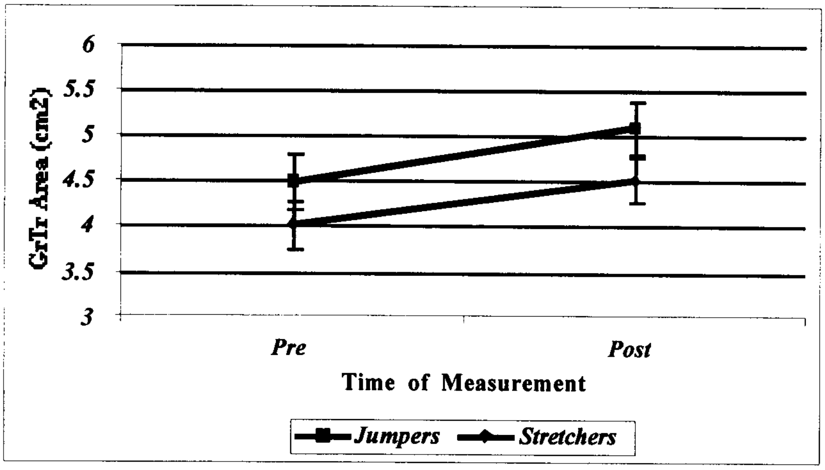
Figure 3. Bone Area Presented as Absolute Values by Group for FN (A), GrTr (B), TH (C), and LS (D) Represented as Absolute Values at Baseline (pre) and the Completion of the Seven Month Intervention (post).

**A**



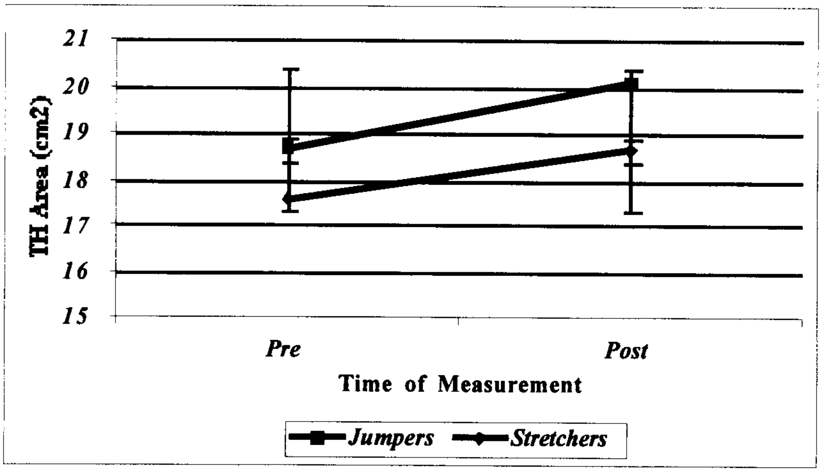

*No significant difference by group for FN area at baseline or the completion of the intervention (p >.05).

**B**



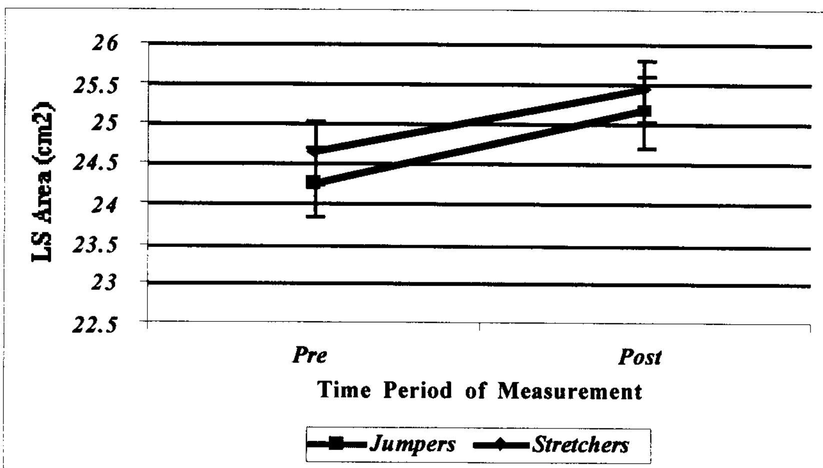

*No significant difference by group for GrTr area at baseline or the completion of the intervention (p >.05).

C




*No significant difference by group for TH area at baseline or the completion of the intervention (p >.05).

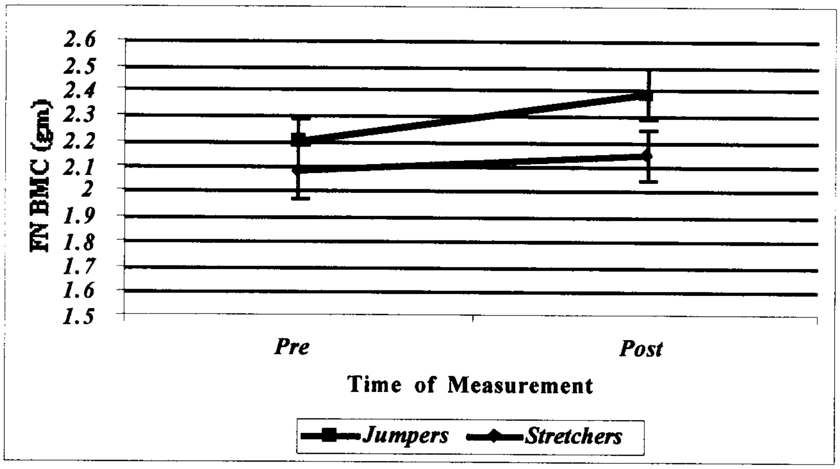
D




*No significant difference by group for LS area at baseline or the completion of the intervention (p >.05).

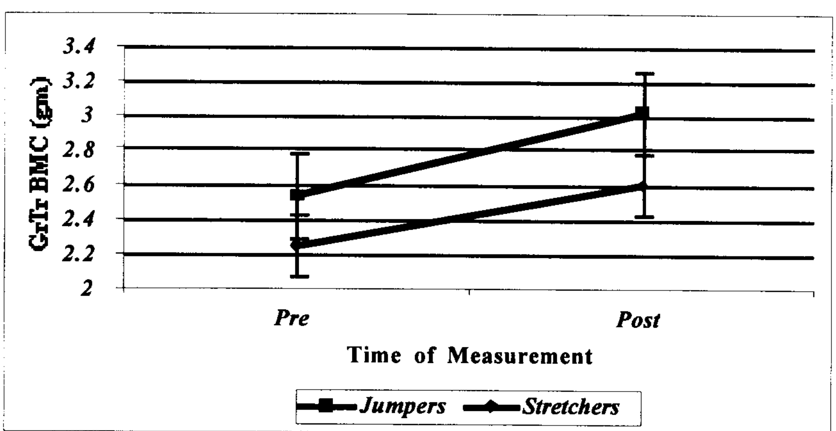
Figure 4. Bone Mineral Content (BMC) by Groups for the FN (A), GrTr (B), TH (C), and LS (D) Represented as Absolute Values at Baseline (pre) and the Completion of the Seven Month Intervention (post).

**A**



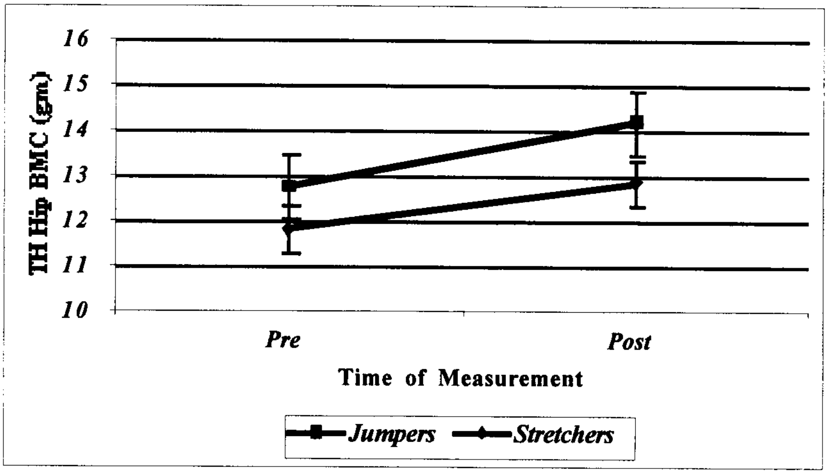

*Significant group difference by group for FN BMC at the completion of the intervention ($p < .04$), with no significant group differences by group at baseline ($p > .05$).

**B**



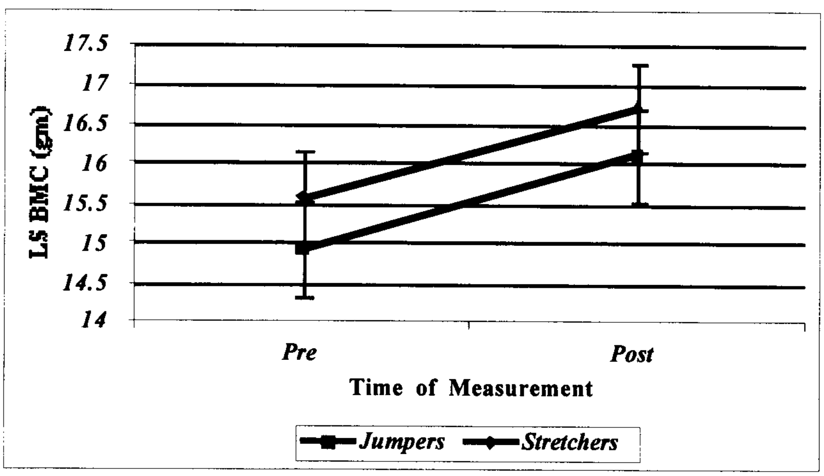

*No significant differences by group for GrTr BMC at baseline or the completion of the intervention ($p > .05$).

**C**




*No significant difference by group for TH BMC at baseline or the completion of the intervention ($p > .05$).

**D**




*No significant difference by group for LS BMC at baseline or the completion of the intervention ($p > .05$).

Physical Activity Status

Hours of weight bearing physical activity were not significantly different between groups ($p > .05$) (table 4). Boys were found to participate in more weight bearing physical activity per week than girls ($p < .05$). Further non of the children engaged in tennis, aerobics, or weight training. Soccer was reported to be the primary team sport with 61% of the jumping group, and 50% of the stretching group engaged in this activity. A total of 12 jumpers (8 boys, 4 girls) and 9 stretchers (6 boys, 3 girls) participated in a team sport of soccer, baseball, or basketball during the exercise period. 1 girl in each exercise group took dance lessons ( 1hr/week), and 1 girl in each group took gymnastics lessons (1 hr/week). No boys reported engaging in dance, ballet, or gymnastics. Television viewing was not significantly different between groups or gender based on the total number of hours of television viewed on both school nights and non school nights (table 5).

Table 3. Physical Activity by Group and Gender Presented as mean ± SD.

| | Jumpers (n=18) | Stretchers (n=16) | Boys (n=18) | Girls (n=16) |
|---|---|---|---|---|
| Baseline (h/week) | 6.2 ± 2.7 | 5.7 ± 3.6 | 6.8 ± 2.6 | 6.7 ± 2.9 * |
| Post Intervention (h/week) | 6.1 ± 2.9 | 5.8 ± 3.2 | 5.5 ± 2.8 * | 6.7 ± 2.9 |

*(p < .05)

Table 4. Television Viewing by Group Represented by the Total Number of Childrenin each Category of Television Viewing at Baseline and the Completion of the Intervention.

| | Jumpers (n=18) | Stretchers (n=16) |
|---|---|---|
| Baseline | | |
| School Nights (hrs/week) | | |
| none | 6 | 3 |
| .5-1 | 6 | 8 |
| 1.5-3 | 5 | 4 |
| 3.5-5 | 1 | 0 |
| 5+ | 0 | 1 |
| Non-school Nights | | |
| none | 5 | 2 |
| .5-1 | 5 | 6 |
| 1.5-3 | 7 | 7 |
| 3.5-5 | 1 | 0 |
| 5+ | 0 | 1 |
| Post Intervention | | |
| School Nights (hrs/week) | | |
| none | 2 | 2 |
| .5-1 | 3 | 1 |
| 1.5-3 | 11 | 10 |
| 3.5-5 | 1 | 2 |
| 5+ | 1 | 1 |
| Non-school Nights | | |
| none | 2 | 2 |
| .5-1 | 3 | 0 |
| 1.5-3 | 10 | 11 |
| 3.5-5 | 2 | 3 |
| 5+ | 1 | 0 |

Calcium Intake

Calcium intake was not significantly different between groups based on the information derived from the general health and physical activity questionnaire ($p > .05$), and there were no gender differences, or group by gender interactions found for calcium intake ($p > .05$). Jumpers had a mean intake of 559.5 mg ± 257.6 and stretchers had a mean intake of 692.5 mg ± 269.5 6. Boys has a mean intake of 589.06 mg ± 261.37, and girls had a mean intake of 659.10 mg ± 278.64.

# DISCUSSION

We sought to evaluate the effects of a highly specific, high load exercise program on bone mass in pre-pubescent boys and girls. Results revealed that children who performed 100 jumps 3 times/week at approximately 8x body weight increased mineral content in the femoral neck which was 8.02 ± 5.12 greater than controls. Since approximately 50% of all hip fractures occur at this site, higher peak bone mass at the femoral neck could prevent hip fractures in later years. These findings support our hypothesis that bone mass at the hip would be significantly greater in children who engaged in high-impact loading versus those children who performed minimal impact activity. A trend for increased bone mineral content and area was observed at the trochanter and total hip, and may have reached statistical significance with more subjects. The clear lack of response at the spine is an equally important finding as the forces were likely absorbed by the lower extremities and never reached the spine.

The primary strength of this study was that a highly-specific, short duration jumping intervention was capable of increasing bone mineral content at the femoral neck, with a trend for increased bone area at this site. This is the first high-impact loading intervention in children to target one specific exercise as a means of increasing bone mass at a clinically relevant fracture site. Numerous intervention studies encompass several different modes and intensities of exercise, making it difficult to ascertain the specific exercise responsible for stimulating skeletal mineralization. The jumping exercises performed in our study only took 10 minutes to complete, and all jumps were performed in a unilateral direction in an effort to identify one specific exercise capable of increasing bone mineral content and bone area. The small number of loading cycles necessary to stimulate an osteogeneic effect at the femoral neck in our study is supported by both human studies in premenopausal women (24) and animal studies (63, 64). Work by Heinonen and coworkers (1996) reported that premenopausal women had a small (1%), but significant increase in femoral neck BMD as a results of participating in an aerobic jump/step program three times per week for 20 minutes. Similarly, animal studies conducted with female rats have found that as few as 5 and as many as 100 jumps performed 5 times per week are effective in increasing the fat free dry weight of the femur and tibia (63, 64). Additionally, Bassey and Ramsdale (1994) found that as few as 50 heel drop jumps per day was adequate to stimulate an increase in trochanteric bone mass by 3.4%, with a trend for increased BMD at the femoral neck. Therefore, the significant increase in skeletal mineralization found in our study and others lends evidence that as little as 50-100 jumps performed at least 3 times per week can induce bone hypertrophy even through the exercise program only requires a short period of time to complete. This short period of time required to conduct this program (10 minutes) would allow fairly easy incorporation into elementary school programming.

Other strengths of this study include randomization, and the pubertal status of the children. First, the randomized design allowed us to control for children self selecting treatment groups. Although only one other prospective intervention has been performed to date in pre-pubescent children, this is the first prospective intervention study in children to utilize a randomized controlled design. Secondly, all children who participated in this study were classified as tanner stage 1 which indicates no secondary signs of sexual maturation, and thus no signs of puberty. The fact that all children remained in the same tanner stage for the entire duration of the study aided in minimizing growth factors such as significant increases in height, weight, body fat, and hormonal status which can easily confound the influence of exercise on bone in more progressive stages of development. Recently Morris and coworkers (1997) found that resistance training effectively increased bone mass at both the hip and spine; however, it is important to note that several tanner stages were represented in this study which makes it more difficult to separate the influences of puberty, from that of the resistance training intervention.

It is important to discuss the limitations of this exercise intervention study. First we had a relatively small sample size which may have limited our ability to identify changes at other sites such as the greater trochanter and total hip. Future studies need to examine this type of training program in a larger population to determine the ability for jumping to increase bone mass at the trochanter and total hip. Secondly, it is important to note that the intervention performed in our population pertains to children who are fairly active, with a majority of the children engaging in some form of physical activity. Due to the small number of subjects in our sample we were unable to identify changes in bone in those children classified as being non-active children. Third, although specific guidelines were used to teach the participants how to execute a proper landing, not all children conformed to those guidelines. Due to the high number of jumps that were performed during a short period of time at each exercise session, some children became fatigued by the end of the jumping classes which altered their jumping form. Differences between children were noted for the angle of knee flexion, the type of landing that was used, and the ability to maintain flatfooted landings. Additionally, as the children in this study became more comfortable with the jumping program the manner in which the jumps were executed may have changed, leading to lower force generation at the ground.

Although researchers are aware that high impact exercise typically produces the greatest gains in bone mass, the specific landing strategies that should be performed to elicit an osteogenic response are not clearly understood. The fact that only the femoral neck was found to respond to the exercise intervention raises an important issue regarding the type of landing strategies that were used by the participants in the jumping group. Researchers have found that depending on the landing strategy that is used the ground reaction forces will change over time, and the manner in which a novice executes a jump will be different than an experienced jumper (10, 25). Based on biomechancial research that has investigated both the ground reaction forces and mechanical loads utilized by novice and elite gymnasts, the participants in this study were taught to land flatfooted, with their knees bent at a joint angle less than 30 degrees. The basis for the jumping style employed in the present study is supported by biomechanical research performed in gymnasts and other athletes who perform activities which require high-impact landings. Kinematic and kinetic analyses of different landing strategies in sports such as gymnastics, basketball, and volleyball (12, 34, 42) have found that landing flat footed, with a small (<30) degrees) joint angle at the hip, knee, and ankle produces higher landing forces than either a heal or toe landing. Thus, the high force, rigid landings imposed on the skeletal system for an athlete that lands from various heights are extraordinarily high, and are believed to be the key osteogenic stimuli that produce the high bone mass values that have been reported in the literature to date (1, 4, 13, 20, 23, 41, 46, 57).

Our findings that mineral content of the femoral neck was greater in boys compared to girls, and that gender differences were not observed at the lumbar spine were not surprising. Other investigators have reported no gender differences at the lumbar spine in prepubertal children (18, 30, 33) but significant gender differences at the hip, specifically femoral neck (8, 9,15, 30,33,48,49, 69). The site specific gender differences noted in this study, and others suggests that the types of weight bearing activities that are performed during childhood play an important role in the development of bone mass at specific skeletal sites. It is not clearly understood why males may display greater bone mineral content at the femoral neck than to girls; however it may be related to the types of physical activities that boys engage in compared to girls. In our study boys were found to engage in significantly more hours of weight bearing physical activity per week than were girls. Although gender differences were not found in our study for the lumbar spine, some researchers have found boys to have larger vertebrae than girls during prepubertal years (17), however, mineral content does not appear to be significantly different.

Although anthropometric characteristics (height, weight, and body fat) did not change in either group during the seven month period, they did increase over this time period. This supports previous work that anthropometric characteristics increase with advances in pubertal development (11, 19). With respect to changes in body composition there were no significant differences or trend between groups. This was to be expected since the mode and intensity of the training was not designed to reduce body fat. It is necessary to develop exercise programs that avoid reduce body fat in order to prevent the delay of menarche, and other developmental processes. Sex differences are generally not found during childhood, but become more apparent during puberty (19, 47). Some researchers have found that gymnastics training has the potential to reduce body fat, and height and weight gains that meet the normal confines of growth (62). It is important to recognize that the exercises in this study did not impair the children from making progress in factors such as height, weight, and body fat which are important for the initiation the pubertal process.

The primary ethnicity in this study was Caucasian; however, a few other races are represented. Due to the small sample size in this study it was not possible to examine the influence of ethnic differences. However, all children in this study fell within the normal ranges for BMC and bone area when compared to Caucasian children (8,9, 33, 50). It is not clear at this time if ethnic difference in bone mass are evident during childhood. Examinations of white and black children from Johannesburg, South Africa found no significant differences at the lumbar spine for BMC or BMD (43). The most significant ethnic differences found during childhood are found between black and white children (66), where as Asian, Hispanic, and white children have been noted as having similar bone mass at the lumbar spine and femoral neck (43, 66). In our sample we did not have any children who were of black descent.

We did not evaluate bone mineral density as it does not account for changes in bone area that occur as a result of increases in height and weight in a growing (7). For example, a child may increase the area of the bone, but maintain the same mineral content, or a child may increase the content of the bone and maintain the same area. Additionally, it is problematic to use BMD as a sole predictor of the success of an exercise intervention program in growing children because BMD does not correct for volumetric density. Although models have been developed that take into account the area of the bone, such as bone mineral apparent density (BMAD) equations, these equations have a high margin of error making it difficult to determine the main effects of exercise on bone mass (22, 37).

Implementing this type of exercise program in children may present concern for injuries that may result. However, it is important to note that the majority of injuries that occur from high impact loading activities occur when landings are performed incorrectly (42). In the present study no injuries occurred. Although children occasionally complained that their knees hurt them; this was generally attributed to other factors such as a previous fall, injury during recess, or sporting injury. Therefore, the intensity and frequency of the exercises performed in this study were viewed as being safe for children of this age group.

This study represents the first prospective evidence that high impact jumping exercises can effectively increase bone mass at the femoral neck. The response found at the femoral neck in our study and that of others supports the theory by Rubin and Lanyon (1985) that bone has the ability to increase in strength and mass by increasing the magnitude of the strain, and reducing the number of loading cycles. To date there are no prospective interventions in children with which the results of this study can be compared; however, results from our study support findings that weight-bearing activity is necessary to produce an increase in bone mass, with increases being observed in children as young as 7 years old (4, 13, 54). The jumping exercises performed in this study take a relatively short period of time to complete, and could easily be implemented into physical education programs. Therefore, the inclusion of jumping exercises into regular PE class may aide in offsetting the deleterious effects of osteoporosis in later adult years.

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# CONCLUSION

Osteoporosis is a debilitating disease characterized by low bone mass and skeletal fragility (Melton, 1996), with the predisposition of osteoporosis developing during childhood (Slemenda et al., 1991). Low bone mass is one of the largest contributing factors associated with the risk for fractures (Fassler & Bonjour, 1995; Melton et al., 1996). Although fracture incidence during childhood has not been linked to lower bone mass values directly, some researchers have found that children who sustain fractures have bone mineral density values below what is normal for a specific age group (Hillman, 1996). Current prevention strategies emphasize active participation in weight-bearing physical activity to help slow the normal aging processes, and maintain the integrity of the skeletal system for a longer period of time (Greenspan et al., 1994).

Reducing the incidence of osteoporosis and osteoporotic related fractures stems from the amount of bone mineral accrued during childhood, also refereed to as peak bone mass. The capacity to increase peak bone mass not only includes factors such as adequate nutrition and proper hormonal balances, but researchers have provided direct evidence that physical activity influences peak bone mass attainment. Physical activity has been advocated as one preventive strategy for increasing peak bone mass, and reducing the onset of osteoporosis. Incorporating high impact physical activity, such as jumping into a child's normal daily routine may aide in decreasing the incidence of osteoporosis in later adult years.

Our study has provided preliminary evidence that high impact exercise performed during childhood may increase bone mass at clinically relevant sites such as the femoral neck. The results of our study bring us closer to obtaining the appropriate intensity, frequency, and duration necessary to stimulate an increase in bone mass during childhood. The exercise program in this study was unique because it only required ten minutes to complete 100 jumps, three times per week. This type of short duration, high intensity exercise protocol provided a sufficient osteogenic stimuli for the femoral neck in both boys and girls. The fact that a highly specific exercise was able to make site specific increases in bone mass will help in the promotion of bone loading activities to be incorporated into physical education programs. The ability for these exercises to increase bone mass lends evidence for the continued support of physical education programs worldwide. In closure, implementing healthy life-style behaviors must start during childhood in order to make strides towards reducing the incidence of osteoporosis and osteoporotic fractures.

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# APPENDICES

# APPENDIX 5.1

# LIST OF ABBREVIATIONS

## Abbreviations

| | |
|---|---|
| BMD | Bone Mineral Density |
| BMC | Bone Mineral Content |
| FN | Femoral Neck |
| GrTr | Greater Trochanter |
| TH | Total Hip |
| LS | Lumbar spine ($L_{2\text{-}4}$) |
| DXA | Dual Energy X-ray Absorptiometer |
| ANOVA | Analysis of Variance |
| ANCOVA | Analysis of Covariance |
| yrs. | Years |
| cm | Centimeters |
| kg | Kilograms |
| p | Significance Level |
| hrs. | Hours |
| MES | Minimum Effective Strain |

# APPENDIX 5.1

# IRB APPROVAL, INFORMED CONSENT FORMS

OREGON STATE UNIVERSITY

**Report of Review** COPY

TO: Christine Snow, ExSS

COPY: Robyn Fuchs

RE: The effects of jumping on growing bones in children.

The referenced project was reviewed under the guidelines of Oregon State University's Committee for the Protection of Human Subjects and the U.S. Department of Health and Human Services. The committee has **approved** your application. The informed consent form obtained from each subject should be retained in program/project's files for three years beyond the end date of the project.

Any proposed change to the protocol or informed consent form that is not included in the approved application must be submitted to the IRB for review and must be approved by the committee before it can be implemented. The approval of this application expires upon the completion of the project or one year from the approval date, whichever is sooner.

Warren N. Suzuki (signature)    Date: 04/18/97

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

## EFFECTS OF JUMPING ON GROWING BONES IN CHILDREN
## Informed Consent for Stretching Group

Currently it is not well known how physical activity affects bone growth in childhood to delay the onset of osteoporosis and the risk for fractures in later years. However, it is becoming increasingly apparent that impact activities, such as jumping are important for building bone. The reduction in bone strength which occurs with age is primarily due to the loss of bone mineral density. In this exercise study we will be exploring the effect that jumping exercises have on increasing both the mass and strength of bone, as well as their effect on increasing physical fitness levels. Bone mass in children who jump will be compared to children who perform stretching exercises to determine the effects of high impact exercise on bone growth and development.

My child has been invited by Dr. Christine Snow (Principal Investigator) and Robyn Fuchs (Student Investigator) to participate in this study looking at the effect jumping exercises have on increasing bone mass in children ages 7-9 years. I am aware that this study will last for 6-months, from September (1997) to April (1998). It has been explained to me that my child will not be jumping, but will be asked to participate in the following: (1) stretching exercises 3 times per week for 15 minutes during a regularly scheduled time at Harding Elementary School (2) Vertical jump test to asses muscle power. This test will be completed at Oregon State University. I received a description of this physical fitness test during the informational meeting and in the packet that was handed out; (3) Bone mineral testing of the hip and lumbar spine (lower back) will be done at Oregon State University. (4) I will be keeping an activity log for my child that will include activities that my son/daughter participates in on a regular basis; (5) I will be asked to complete a Food Frequency Questionnaire in September and in April; (6) I will be asked to help my son/daughter complete a physical activity questionnaire, and a health and physical activity history questionnaire in September and in April; (7) My child will have their body composition measured at Oregon State University in September and April

It is the investigator's experience that children performing these exercises have not been injured as a result of participation. I understand that the University does not provide a research subject with compensation or medical treatment in the event a subject is injured, or as a result of participation in the research project.

It has been explained to me that if my child is in the control group he/she will be involved in stretching exercises 3 times per week for approximately 10-15 minutes. The stretching group will be led by a qualified instructor from this research project, and/or the physical education teacher. Proper guidance will be given to ensure that the exercises are performed correctly, and to decrease the chance for injury. Alternative activities will be provided if my child is unable to participate in the stretching exercises.

It has been explained that the bone mineral testing will require my child to lie quietly on a large x-ray table for six minutes for the hip and spine scans. Additionally, I understand that the parent/guardian is responsible for providing transportation for my child on testing days both to and from the OSU Bone Research Laboratory.

The technique that will be used to assess bone mineral content gives an accurate measure of bone density with a very low exposure to radiation. It has been explained that this radiation dose is considered safe to administer on several occasions to children in this age group. No injections are given and there are no known hazards from radiation at such a low level. The amount of radiation that my child will receive is the same as what they would be exposed to during a plane trip across the country. The use of dual energy x-rayon children has been used effectively and safely in many studies, resulting in the development of standard values for children of different ages.

I understand that my child will be having his/her body composition measured using skinfold calipers. I have been told that this testing procedure will not hurt my child. The researchers of this study will only be measuring skinfold thickness of 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 proven as a safe and reliable way to measure overall body composition.

I understand that I will be recording my child's food intake on a food questionnaire that will take approximately 20 minutes to complete.

I understand 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.

I have been informed and understand the 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. Questions about the research or any aspect of my child's participation should be directed to Dr. Snow at 737-6788 or Robyn Fuchs at 737-6785. I have read the above information and agree for my child to participate.

Please check the box that indicates what you will allow your child to complete for this study. *Completing all the bone scans, muscular power test, body composition and stretching exercises will give your son/daughter full participation in the study.

*Stretching/Bone scans, muscular power test, body composition ☐
Stretching/Bone scans, muscular power test, no body composition ☐
Stretching/No testing ☐
My child will not participate in this study ☐

Subject Signature________________________________ Date________

Parent/Guardian Signature________________________________ Date________

Investigator's Signature________________________________ Date________

## EFFECTS OF JUMPING ON GROWING BONES IN CHILDREN
## Informed Consent for Jumping Group

Currently it is not well known how physical activity affects bone growth in childhood to delay the onset of osteoporosis and the risk for fractures in later years. However, it is becoming increasingly apparent that impact activities, such as jumping are important for building bone. The reduction in bone strength which occurs with age is primarily due to the loss of bone mineral density. In this exercise study we will be exploring the effect that jumping exercises have on increasing both the mass and strength of bone, as well as their effect on increasing physical fitness levels. Bone mass in children who jump will be compared to children who perform stretching exercises to determine the effects of high impact exercise on bone growth and development.

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 ages 7-9 years. I am aware that this study will involve a 6-month period, from September (1997) to April (1998). It has been explained to me that my child will be asked to participate in the following: (1) Jumping exercises incorporated into my son/daughters pre-existing physical education program; (2) A vertical jump test to asses muscle power. This test will be completed at my son/daughters elementary school. I received a description of the vertical jump fitness test during the informational meeting and in the packet that was handed out; (3) Bone mineral testing that will be done at Oregon State University and will test the lumbar spine (lower back) and hip; (4) I will be keeping an activity log for my child that will include activities that my son/daughter participates in on a regular basis; (5) I will be asked to complete a Food Frequency Questionnaire in September and in April; (6) I will be asked to help my son/daughter complete a physical activity questionnaire, and a health and physical activity history questionnaire in September and in April (7) My child will have their body composition measured at Oregon State University in September and April.

It has been explained to me that if my child is in the exercise program he/she will be involved in jumping exercises that will be incorporated into their regular physical education class. I understand that the jumping activities will take approximately 10-15 minutes during each physical education class. The class will be led by a qualified instructor from this research project, and/or the physical education teacher. Proper guidance will be given to ensure that the exercises are performed correctly, and to decrease the chance for injury. Alternative activities will be provided if my child is unable to participate in the jumping exercises.

I understand that although the possibility of injury from either the jumping exercises or the muscular power test may exist, the risk for injury is minimal. Each class will be carefully monitored, and will include a good warm-up and cool-down. It is the investigators' experience that children performing these exercises have not been injured as a result of participation. I understand that the University does not provide a research subject with compensation or medical treatment in the event a subject is injured, or as a result of participation in the research project. It has been explained that the bone mineral testing will require my child to lie quietly on a large x-ray table for six minutes for the hip and spine. Additionally, I am aware that as the parent/guardian I am responsible for transporting my son/daughter to and from the OSU Bone Research Laboratory for the bone scans.

The technique that will be used to assess bone mineral content gives an accurate measure of bone density with a very low exposure to radiation. The radiation dose is considered safe to administer on several occasions to children in this age group. No injections are given and there are no known hazards from radiation at such a low level. The amount of radiation that my child will receive is the same as what they would be exposed to during a plane trip across the country. The use of dual energy x-ray on children has been used effectively and safely in many studies, resulting in the development of standard values for children of different ages.

I understand that my child will be having his/her body composition measured using skinfold calipers. I have been told that this testing procedure will not hurt my child. The researchers of this study will only be measuring skinfold thickness of 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 proven as a safe and reliable way to measure overall body composition.

I understand that I will be recording my child's food intake on a food questionnaire that will take approximately 20 minutes to complete.

I understand 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.

I have been informed and understand the 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. Snow at 737-6788 or Robyn Fuchs at 737-6785. I have read the above information and agree for my child to participate.

Please check the box that indicates what you will allow your child to participate in during their PE class this year. *Jumping exercises and completing the muscular power test, bone scans and body composition testing would give your son/daughter full participation in the exercise class and study.

| | |
|---|---|
| *Jumping/Bone scan, muscular power test, body composition | ☐ |
| Jumping/Bone scan, muscular power tests, no body composition | ☐ |
| Jumping/No testing | ☐ |
| My child will not participate in this study | ☐ |

Subject Signature________________________________ Date________

Parent/Guardian Signature__________________________ Date________

Investigator's Signature____________________________ Date________

## ORAL SCRIPT FOR CHILDREN IN STRETCHING GROUP

I know that I will be doing stretching exercises for 15 minutes three times per week this school year. Robyn Fuchs, a graduate student from Oregon State University (OSU) will lead my exercises.

I will be doing physical fitness tests, a body composition test, and bone strength tests. My parents will need to take me to OSU to do these different tests.

I will do a vertical jump test and leg press test for my physical fitness tests. I will be shown how to do these tests to make sure I do it right and to help from hurting myself.

For the bone strength testing I will need to lay very still on an x-ray table for about 6 minutes for scans of my hip and spine. I have been told that the x-ray will not hurt me (researcher will show bone scan machine to child).

I have been told that I will have measurements done on my arm and back to find out how thick my skin is. I have been told that the calipers (researcher will show calipers to child) that will be used will not hurt me.

I will also tell about what I eat and the activities that I will be doing outside of my PE class. My parents will help me fill out the sheets for both what I eat and the activities I do.

I know that it is my choice to participate in this study. Further questions that I may have can be answered by Robyn Fuchs at 737-6785 or Christine Snow at 737-6788.

The above information has been read to my child and he/she agrees to participate.

Parent/Guardian's Signature______________________ Date____
Investigator's Signature___________________________ Date____

# APPENDIX 5.2

# GENERAL PHYSICAL ACTIVITY AND HEALTH QUESTIONNAIRE

## OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY
**Heath and Physical Activity History**

| | |
|---|---|
| ______________________________ | ______________ |
| 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.___________

_________________________________

<u>PAST HISTORY</u> (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 | ______ |

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

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

Other______________________________
______________________________
______________________________

<u>PRESENT SYMPTOMS REVIEW</u> (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______________________________
______________________________

<u>MEDICAL/HEALTH AND PHYSICAL ACTIVITY QUESTIONS</u>

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?
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?_________

PHYSICAL ACTIVITY

List all sports or activities in which your child has participated during the past year: (Examples include aerobics, tennis, soccer, softball, dance, football, hiking, swimming, biking, etc.) Use the back of this paper if necessary.

| ACTIVITY | AVE # HR./WK | AVE # MONTHS/YR. |
|---|---|---|
| Ex. Soccer | 1 | 6 |

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 5.3

## BODY COMPOSTION ASSESSMENT SHEET and EQUATIONS

**OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY**
**Body Composition Assessment Sheet**

Name:________________________________

General Instructions: Measure to the nearest 1.0 mm using Lang Calipers

**********************************************************************

Date:____________________

Skinfold Measurements

1) Triceps skinfold
- Trial 1____________mm
- Trial 2____________mm
- Trial 3____________mm
- Average____________mm

2) Subscapular skinfold
- Trial 1____________mm
- Trial 2____________mm
- Trial 3____________mm
- Average____________mm

Sum of triceps + subscapular skinfolds = ______________mm

**********************************************************************

Date:____________________

Skinfold Measurements

1) Triceps skinfold
- Trial 1____________mm
- Trial 2____________mm
- Trial 3____________mm
- Average____________mm

2) Subscapular skinfold
- Trial 1____________mm
- Trial 2____________mm
- Trial 3____________mm
- Average____________mm

Sum of triceps + subscapular skinfolds = ______________mm

## 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

Age = years

# APPENDIX 5.4

# PHYSICAL ACTIVITY QUESTIONNAIRE

**OREGON STATE UNIVERSITY BONE RESEARCH LABORATORY**
**Physical Activity Questionnaire**

*Children's Questionnaire*

Child's Name:______________________________ Date:______________

1. Frequency of physical education classes (times per week).
   0 ❐ 1 ❐ 2 ❐ 3 ❐ 4 ❐ 5 ❐ __________other

2. Length of physical education classes (minutes).

| | | | | | |
|---|---|---|---|---|---|
| 0 | ❐ | <20 | ❐ | 21-25 | ❐ |
| 26-30 | ❐ | 31-35 | ❐ | 36-40 | ❐ |
| 41-45 | ❐ | 46-50 | ❐ | 60+ | ❐ |

2 Proportion of class time spent in intense activities (activities that make you breathe hard).

| | | | | | |
|---|---|---|---|---|---|
| none | ❐ | 1/4 | ❐ | 1/2 | ❐ |
| 3/4 | ❐ | all | ❐ | | |

4. Television watched.

| School Nights | | Nonschool Nights | |
|---|---|---|---|
| None | ❐ | None | ❐ |
| 1/2 - 1 | ❐ | 1/2 - 1 | ❐ |
| 1.5 - 2 | ❐ | 1.5 - 2 | ❐ |
| 2 - 2.5 | ❐ | 2 - 2.5 | ❐ |
| 3 - 3.5 | ❐ | 3 - 3.5 | ❐ |
| 3.5 - 4 | ❐ | 3.5 - 4 | ❐ |
| 4 - 4.5 | ❐ | 4 - 4.5 | ❐ |
| 4.5- 5 | ❐ | 4.5 - 5 | ❐ |
| 5+ | ❐ | 5+ | ❐ |

5. Hours per week spent in each listed activity.

| | 0 | 1-2 | 3-4 | 5-6 | 7-8 | 9-10 | 11+ |
|---|---|---|---|---|---|---|---|
| Cycling | __ | __ | __ | __ | __ | __ | __ |
| Swimming | __ | __ | __ | __ | __ | __ | __ |
| Running | __ | __ | __ | __ | __ | __ | __ |
| Running games | __ | __ | __ | __ | __ | __ | __ |
| Weight Lifting | __ | __ | __ | __ | __ | __ | __ |
| Aerobic dance | __ | __ | __ | __ | __ | __ | __ |
| Walking | __ | __ | __ | __ | __ | __ | __ |
| Baseball | __ | __ | __ | __ | __ | __ | __ |
| Basketball | __ | __ | __ | __ | __ | __ | __ |
| Soccer | __ | __ | __ | __ | __ | __ | __ |
| Tennis | __ | __ | __ | __ | __ | __ | __ |
| Other | __ | __ | __ | __ | __ | __ | __ |

6. Participation in team sports.

| | | | | | |
|---|---|---|---|---|---|
| Baseball/softball | ❐ | Football | ❐ | Basketball | ❐ |
| Gymnastics | ❐ | Swimming | ❐ | Track | ❐ |
| Soccer | ❐ | Tennis | ❐ | Cross-Country | ❐ |
| Volleyball | ❐ | Golf | ❐ | Wrestling | ❐ |

7. Open-ended list. Four most frequent activities. Time spent in each per week.
    1.
    2.
    3.
    4.

*Mother's Questionnaire*

1. Time spent in vigorous activity on an average day (approximate number of hours).

| | | | |
|---|---|---|---|
| None | 1/2 ❐ | 1 ❐ | 2 ❐ |
| 3 ❐ | 4 ❐ | 5 ❐ | _________other |

2. Level of child's activity compared to other children the same age.

| | | | | | |
|---|---|---|---|---|---|
| much less | ❐ | less | ❐ | same | ❐ |
| more | ❐ | much more | ❐ | | |

3. Television watched by the child.

| School Nights | | Nonschool Nights | |
|---|---|---|---|
| None | ❐ | None | ❐ |
| 1/2 - 1 | ❐ | 1/2 - 1 | ❐ |
| 1.5 - 2 | ❐ | 1.5 - 2 | ❐ |
| 2 - 2.5 | ❐ | 2 - 2.5 | ❐ |
| 3 - 3.5 | ❐ | 3 - 3.5 | ❐ |
| 3.5 - 4 | ❐ | 3.5 - 4 | ❐ |
| 4 - 4.5 | ❐ | 4 - 4.5 | ❐ |
| 4.5- 5 | ❐ | 4.5 - 5 | ❐ |
| 5+ | ❐ | 5+ | ❐ |

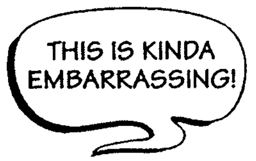
4. Open-ended list. Four most frequent activities for your child. Time spent in each per week.
    1.
    2.
    3.
    4.

# APPENDIX 5.5

# TANNER STAGE SHEETS

# 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**

- *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.*

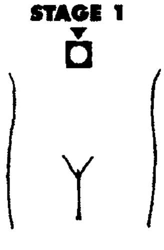
**STAGE 5**

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

---

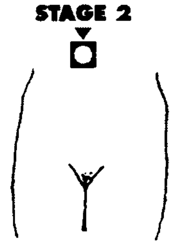
***Another change is to grow pubic hair. Please LOOK at the drawings and READ the sentences below each of them. Then choose the drawing closest to your stage of hair development and FILL IN THE CIRCLE above it.***

**STAGE 1**



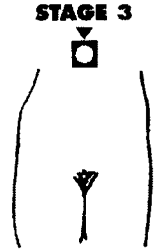
- *There is no pubic hair.*

**STAGE 2**



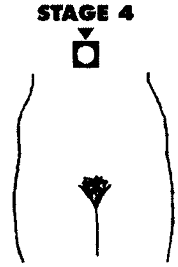
- *There is a little, long, lightly colored hair.*
- *This hair may be straight or a little curly.*

**STAGE 3**



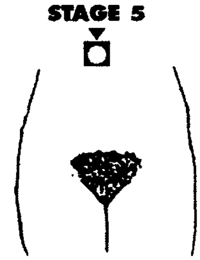
- *The hair is darker, coarser, and more curled.*
- *It has spread out and thinly covers a larger area.*

**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.*

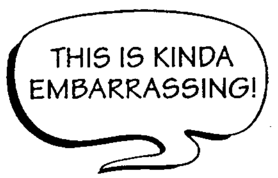
**STAGE 5**



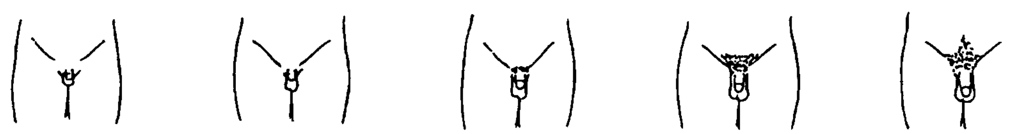
- *The hair is now like that of a grown woman.*
- *The hair often forms a triangle (▽) as it spreads out to the legs.*

# 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.*